A Hydrogeological Study of the Interaction Between Avon River Baseflow and Shallow Groundwater, Christchurch, New Zealand.

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ABSTRACT

The relationship between shallow groundwater levels and Avon River baseflow upstream of Gloucester Street has been investigated. Avon River baseflow is supplied by shallow groundwater-fed springs. Historical and anecdotal information indicate that since European settlement of the Christchurch area in the 1850's, Avon River baseflow has declined. The baseflow decline is attributed to the progressive lowering of the Christchurch area watertable which has caused downstream migration of headwater spring positions and a reduction in spring discharge. Prior to this study minimal historical Avon River flow data existed, and a quantitative estimation of the decline in baseflow is not possible. A management plan for maintaining acceptable baseflow levels in the Avon River is currently being developed by the Canterbury Regional Council. The aim of this study was to provide information on the relationship between Avon River baseflow and shallow groundwater levels to aid baseflow management.

The Christchurch groundwater system is characterised by a watertable aquifer that overlies a series of layered confined aquifers. Direct groundwater discharge into the Avon River is considered to be from both the watertable aquifer and upper most confined aquifer. Groundwater was found to enter the river system by two different mechanisms; seepage through stream bed gravel and artesian spring discharge. Groundwater seepage through streambed gravel occurs where the stream channel intersects the watertable aquifer. Artesian springs occur where water-bearing gravels are overlain by between approximately 1 to 10 m of finer-grained confining sediment. Artesian spring water is thought to flow from both the watertable aquifer and the uppermost confined aquifer. Pipes through the confining sediment connect the spring vent to the underlying water-bearing gravels. When the hydraulic head of the underlying gravel aquifer is above the stream stage artesian spring flow will occur.

Tributary baseflow and shallow groundwater data were collected for the 11 month period, February 1992 to January 1993. In addition, baseflow was separated from the Avon River flow record. Available flow data indicate that mean Avon River baseflow at Gloucester Street from 1980 to 1992 was approximately 1700 l/s. In March 1993 Avon River baseflow was 50% of that in March 1980. Large rainfall events in late-August 1992 caused Avon River baseflow in January 1993 to increase to approximately 77% of the March 1980 value.

Regression analysis established a relationship between both hydraulic head in the upper most confined aquifer and unconfined watertable levels, to Avon River baseflow ($R^2 > 0.8$). The flow hydrograph showed that the daily abstraction of shallow groundwater from beneath the catchment caused an associated reduction in flow. Seasonal fluctuations in spring discharge and baseflow were found to be greater in the western tributaries than the eastern tributaries. This is attributed to the greater seasonal fluctuation of shallow groundwater levels in the western area of the catchment than in the eastern area. From available data the peak in seasonal groundwater levels occurred throughout the study area during the period of 24-27 October 1992. No observable time delay occurred between the seasonal peaks in shallow groundwater levels and Avon River baseflow at Gloucester Street.

In order to sustain acceptable rates of Avon River baseflow, shallow groundwater levels need to be maintained in areas of the catchment were groundwater enters the river. As a first step, the Canterbury Regional Council has placed restrictions on the abstraction of groundwater in areas where springs occur. The information presented in this study on the relationship between shallow groundwater levels and Avon River baseflow confirms the need for management of shallow groundwater levels in areas where groundwater contributes to baseflow. To ascertain the effectiveness of remedial measures continued monitoring of Avon River baseflow and shallow groundwater levels are necessary.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

The baseflow of the urban streams of Christchurch originates from groundwater-fed springs and the drainage of wetland areas. Over historical times, urban development has caused a reduction in total spring contribution and wetland area, with a resultant decline in Avon River baseflow.

Towards the end of the 1980's, changes in the structure and policy of local government facilitated the development of a more sustainable management plan for the city's surface and groundwater resources than existed prior to the late 1980's. The Christchurch City Council, the Canterbury Regional Council and the Department of Conservation are now co-operating in the preparation of a management plan for the Avon and Heathcote rivers and estuaries. The traditional focus of the Christchurch drainage plan was to provide for extreme flood flows. One aspect of the new management plan is to develop management strategies which provide for the maintenance of adequate low flow rates in the rivers. The concern is that a decline in baseflow will jeopardise the recreational, aesthetic and ecological aspects of the streams.

Several possible remedial measures are being considered to sustain adequate baseflow in the Avon and Heathcote rivers. Before any remedial measures are selected, it is necessary to determine the extent of the reduction in baseflow, obtain an understanding of the streams low flow regime and provide a data base upon which the effectiveness of remedial measures can be judged.

The remedial measures that are being considered are:

- setting controls on groundwater levels and/or abstraction rates;
- augmentation of flows from other sources, eg Waimakariri River water via the western water race system, deep groundwater;

- use of ground soakage to dispose of stormwater;
- maintenance and/or enhancement of existing wetlands, creation of new wetlands; and
- modification of some existing land drainage works.

Prior to 1992, minimal historical low flow data of the Avon River existed. The sole low flow study on the Avon River was by Daglish (1985). Two other biological studies of the Christchurch urban streams also incorporate some low flow data (Marshall 1973; Wilson 1980).

1.2 OBJECTIVES

During the summer of 1992 this project was initiated with the following objectives:

- collect low flow data on the tributaries of the Avon River;
- investigate the relationship between Avon River baseflow and the shallow groundwater levels beneath the catchment;
- compare historical data to that collected by this study to ascertain, and where possible quantify, the magnitude of the decline in Avon River baseflow.

Although streamflow rates were known to be dependent on groundwater levels it was not known quantitatively what change in streamflow rates occurred in response to fluctuations in groundwater levels.

The study was limited to the catchment upstream of the Gloucester Street bridge for logistic reasons in data collection. In addition, historical river flow data have been recorded at Gloucester Street.

1.3 FUNDING AND SUPPORT

Financial support for this project was given by Canterbury Regional Council (C.R.C). They also provided historical data, computer facilities, technical expertise, and field

equipment. Historical data was also supplied by the Christchurch City Council (C.C.C).

1.4 THESIS ORGANISATION

This thesis is presented in six chapters. Chapter 2 presents a summary of the history and physical setting of the study area. The hydrological implications of urbanisation are also outlined. In Chapter 3 the Avon River system baseflow data that was collected during this study is presented and discussed. Also in this chapter is an analysis of how the Avon River low flow regime has changed since 1980. Chapter 4 describes the spatial relationship between the near surface hydrogeology and spring occurrence. Chapter 5 discusses the relationship between shallow groundwater levels and Avon River baseflow. Conclusions are presented in Chapter 6. The Appendices contain tables of all the stream flow and groundwater level data that were collected during this study.

Analysis of the hydrological data (including stream flow, groundwater and rainfall) was carried out on the VAX computer system installed at the Canterbury Regional Council using the software packages TIDEDA and SAS. Figures were drafted using AutoCAD™ installed at the Geology Department, University of Canterbury, and using TIDEDA, SAS and Microsoft Excel™. TIDEDA is a software package used for time dependent data storage and analysis and uses a numeric site number for referencing. Although in TIDEDA plots site numbers have been assigned to rainfall and groundwater level records, this study uses the C.R.C. well and rainfall station reference.

Flow data for the Avon River at Gloucester Street, groundwater level data, and rainfall data are archived at the C.R.C. and the C.C.C.

CHAPTER 2 OVERVIEW OF THE AVON RIVER SYSTEM

2.1 PHYSICAL FEATURES OF THE STUDY AREA

2.1.1 LOCALITY

The Avon River is located in Christchurch City on the east coast of the South Island (Figure 2.1). The catchment is 84 km^2 and is composed of 12 named tributaries (and a number of man-made drains). The river flows east, from the northwestern suburbs through the inner city to discharge at the northern end of the Avon - Heathcote Estuary.

2.1.2 GEOLOGY

2.1.2.1 Regional Geology

The geology and stratigraphy of the coastal plains have been documented by a number of authors (Suggate 1958, 1963, 1965, 1968; Wilson 1976, 1986; Brown and Wilson 1988). A recent description of the geology of the Christchurch area is 'Geology of the Christchurch Urban Area' by Brown and Weeber (1992).

The Canterbury Plains are a complex of coalescing fans overlying a basement of Permian to Jurassic Torlesse Super Group rocks. Mid to late Tertiary volcanic activity has left an extinct volcanic complex (Banks Peninsula) at the eastern margin of the plains. The fans were deposited during the late Tertiary and Quaternary periods by eastward-flowing rivers that emerged from the foothills of the Southern Alps. The inland plains are comprised predominantly of gravels, which petroleum exploration bores have shown to be more than 500 m thick. At the coastal margins of the plains, intermittent Quaternary interglacial sea level rises caused the repeated deposition of finer grained marine sediment (Figure 2.1). The fine grained marine sediments inter-finger with the coarser gravels and sands of the coastal fan complex and the result is a layered sequence of gravel aquifers separated by aquitards of relatively less permeable marine sediment.

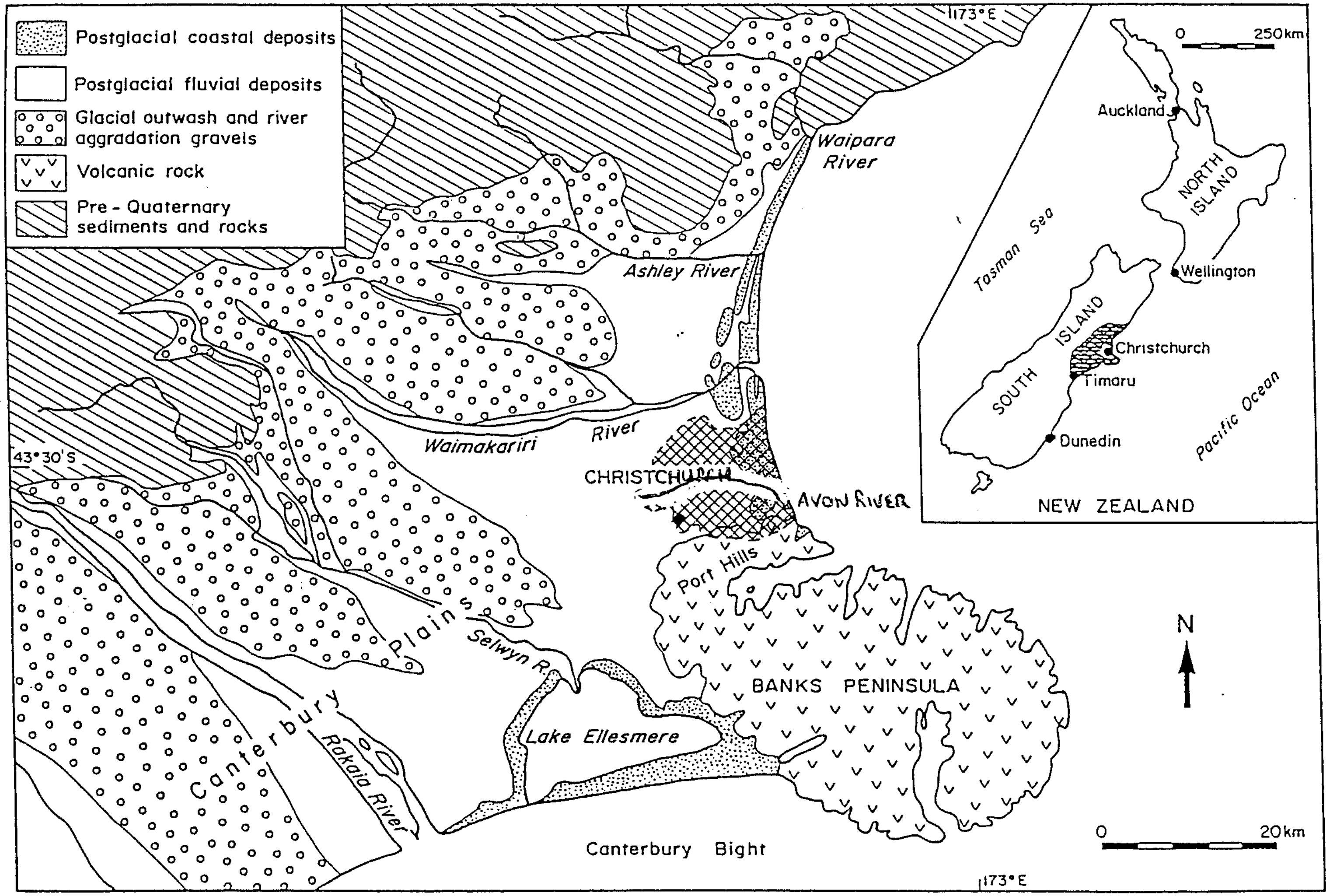


FIGURE 1·1: LOCATION MAP AND QUATERNARY SURFACE DEPOSITS OF THE CANTERBURY REGION
After Brown et al (1988)

2.1.2.2 Late Quaternary Geology

The Avon River catchment and much of metropolitan Christchurch lie on the late Quaternary sediments of the coastal plains. These late Quaternary sediments (from approximately 380,000 years ago to present) have been grouped into stratigraphic units based on subsurface information gained from several hundred well logs. Figure 2.2 shows the layered stratigraphy of gravel aquifers and finer grained aquitards beneath Christchurch. Since it is the upper three formations that are most relevant to the groundwater supply to the Avon River, the remainder of this section will focus upon the geology of the Riccarton Gravels, and the Christchurch and Springston formations.

The coastal late Quaternary sediments are composed predominantly of terrestrial gravels, with minor wedges of marine and dune sands, and estuarine peats and clays (Suggate 1958, 1968; Wilson, 1986). The terrestrial gravels were deposited by the Waimakariri River, as progradational glacial outwash surfaces and interglacial alluvial fans (Wilson 1985). During glaciations, fans of unsorted outwash were deposited on the higher western inland plains, while during interglacial periods, the Waimakariri River entrenched into the inland plains and redeposited the material further downstream. Deposition of the interglacial alluvium of the coastal plains is believed to have occurred within an entrenched flood plain of the Waimakariri River. The flood plain was modified by transient flood channels which deposited channel gravels and sands, and overbank silts and sands. The channel deposits were preserved as longitudinal gravel and sand lenses that vary in dimension both laterally and vertically. With rising inter- and post-glacial sea levels, periodic marine transgressions repeatedly deposited swamp, estuary and lagoon and beach deposits over the alluvial fans.

<u>Riccarton Gravels</u> (Suggate 1958, Brown and Wilson 1988)

During the last glaciations (70 000 - 14,000 years ago), the Riccarton Gravels were deposited behind the eastward retreating shoreline (i.e., on the Bromley Formation). These gravels were deposited in a similar depositional environment as the gravels of the deeper aquifers, that is, outwash rivers building out coalescing fans across the

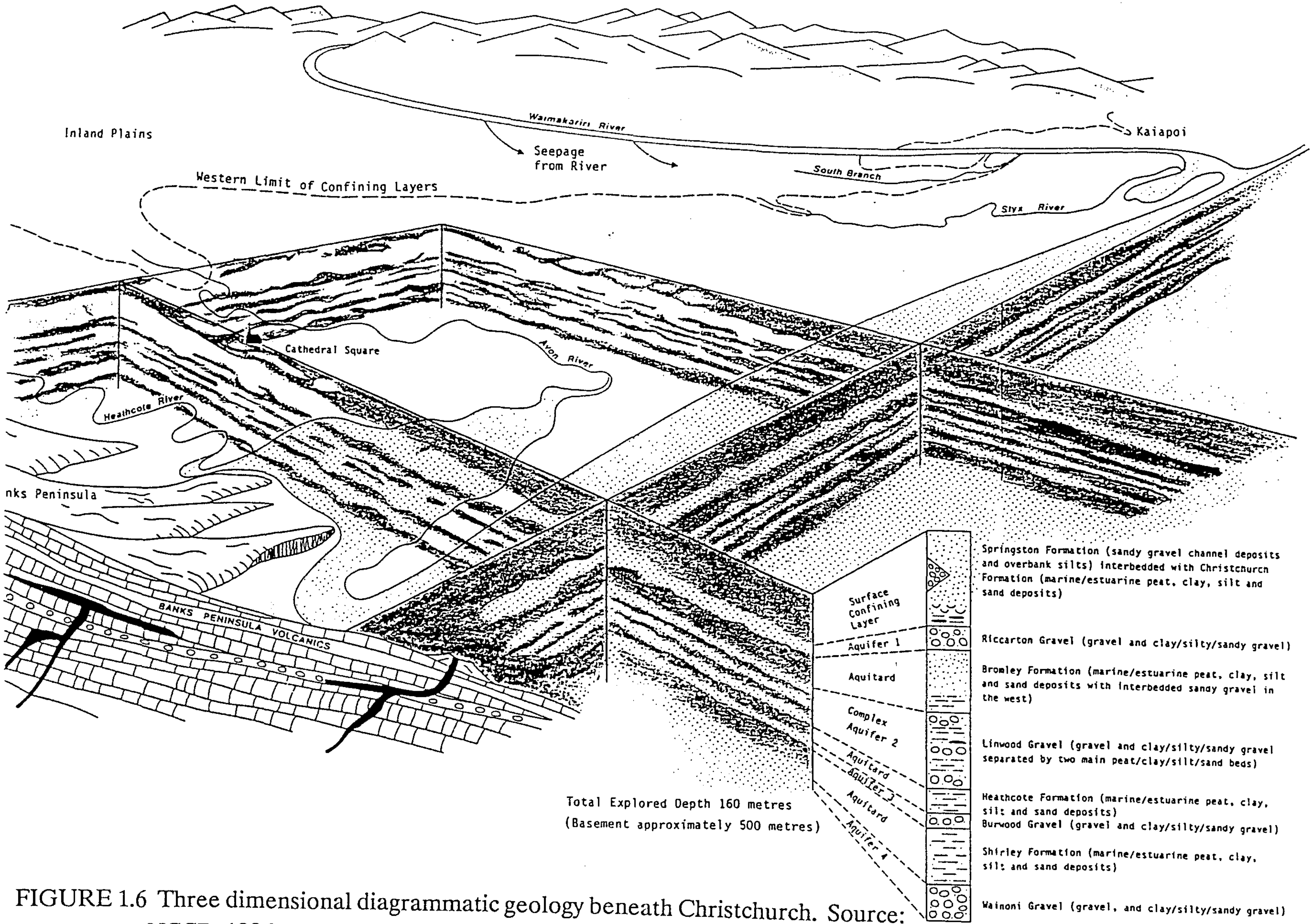


FIGURE 1.6 Three dimensional diagrammatic geology beneath Christchurch. Source: NCCB 1986

Canterbury Plains during periods of low sea level. The depth of the Riccarton Gravels below ground surface varies from 10 to 40 m, and the formation ranges in thickness from a few metres to 20 m. The Riccarton Gravels form the uppermost confined aquifer beneath Christchurch (Wilson 1976). To the west it extends beyond the limit of the confining layer (the fine-grained marine sediments of the Christchurch Formation) and is indistinguishable from the overlying postglacial Springston Formation gravels.

<u>Christchurch Formation</u> (Suggate 1958)

At the end of the last glaciation (approximately 14 000 years ago) the associated rise in sea level led to the deposition of beach, estuarine, lagoon, dune and coastal swamp sediments over the Riccarton Gravels at the margin of the advancing sea (Suggate 1958). These fine grained sediments were termed the Christchurch Formation by Suggate (1958). The Christchurch Formation also incorporates gravel channels that represent historical flood channels of the Waimakariri River. In the Christchurch area, the surface deposits of the Christchurch Formation extend inland to Papanui, Fendalton and Riccarton. It is wedge shaped, thickening from just a few metres in the west to approximately 40m at the New Brighton coast. In the west, the Christchurch Formation interfingers with, and in some places is overlain by, the gravel filled channels of the Springston Formation.

<u>Springston Formation</u> (Suggate 1958, Brown and Wilson 1988)

On the coastal plains, the Springston Formation occurs as a wedge of channel gravel deposits and overbank silts that formed as inland glacial outwash was eroded by the entrenching Waimakariri River and redeposited downstream as alluvium. The gravel of the Springston Formation is finer and more permeable than the older glacial outwash gravels. Postglacial fan surfaces on the south bank of the Waimakariri River have facilitated the subdivision of the Springston Formation into five members (Suggate 1958, Wilson 1989). Within the study area only the Yaldhurst Member is present, and the three lithological units are:

1) overbank silt, the most widespread deposit, with much of it formerly swamp;

2) peat deposits formed in well established swamps (e.g., Marshlands); and

3) gravel flood channels from the Waimakariri River entrenched into the surface of the plains. These channels thin eastwards into sinuous, discrete channel deposits that connect with the headwaters of the Avon, Halswell, Heathcote and Styx Rivers.

In the coastal plains, alternating fine and coarse sediments facilitate separation of the sequences, while inland, sediments are almost entirely composed of gravel without readily identifiable subdivisions. As a result, a west to east correlation of sediments is difficult, although regional cross-sections have been constructed by NCCB (1986) using several hundred well logs.

2.1.3 SURFACE HYDROLOGY

The flat to gently undulating alluvial flood plain of the Waimakariri River rises from sea level to 135 m above mean sea level at Halkett (Figure 2.3), at a slope of about 4 m/km. The steep and rolling Port Hills rise to 500 m above mean sea level. To the west of Christchurch the soils on the plains are very free draining and there is seldom any surface runoff and consequently no distinct drainage pattern. The metropolitan area of Christchurch is 11300 ha. of which about 70% is located on former swamp land or periodic wet land. Drainage of the greater Christchurch area is by the spring fed Styx, Avon and Heathcote Rivers (Figure 2.3). These rivers all rise in the west and drain towards the east coast. Were it not for the extensive drainage provided by these rivers, high watertable and intense rainfall would revert much of the area back to swamp. The inset in Figure 2.3 shows the area illustrated in Figure 2.4. Figure 2.4 shows the contours of the depth below ground surface of the water-table in the surface sediments.

The influence of tidal movement on the Avon River extends upstream approximately 12 km from the estuary. The catchment is very flat, rising to only 30 m above sea level.

The Heathcote River catchment is 103.4 km^2 of which a substantial portion is rural and nearly one-third hill catchment. The Heathcote discharges into the southwest corner of

Figure 2.3 Rivers in the Christchurch Area

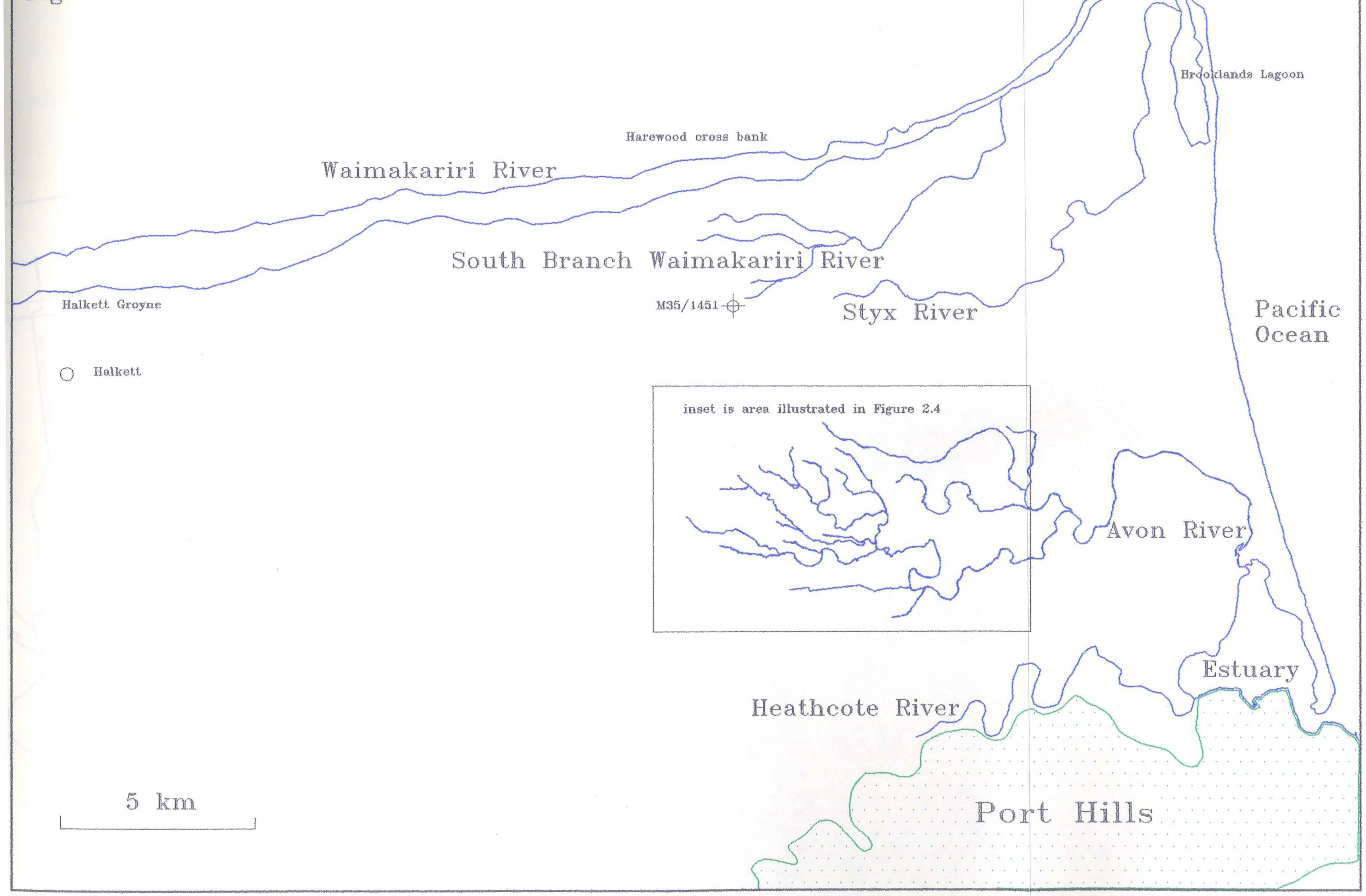
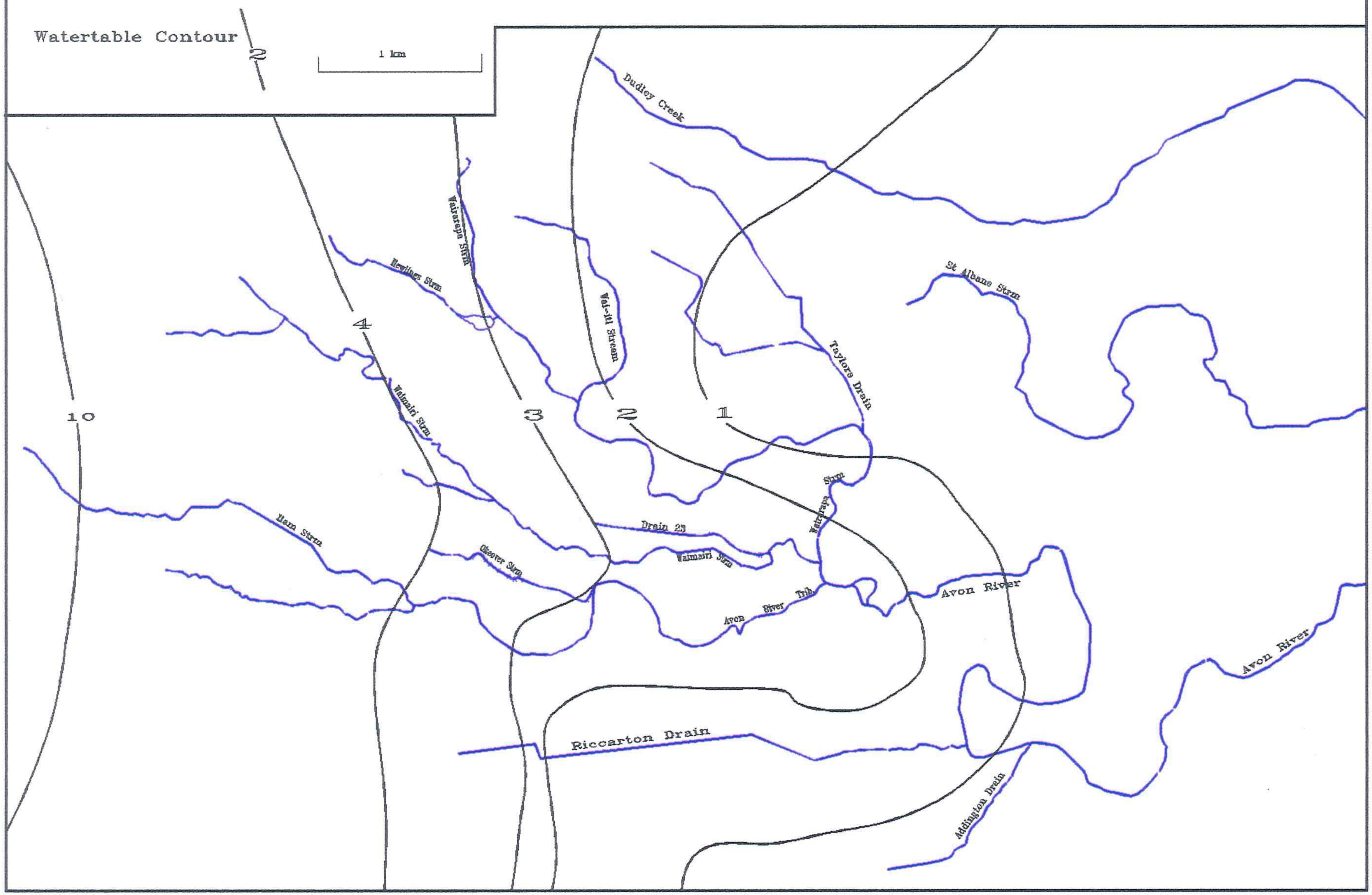


Figure 2.4 Depth to Watertable in Surface Sediments Beneath Christchurch (meters below ground level) (adapted from NCCB 1986)



the Avon - Heathcote Estuary. The influence of tidal movements normally extend approximately 12 km upstream from the estuary.

The Styx discharges into the Waimakariri River near its mouth in the Brooklands Lagoon. Its course is through predominantly rural catchments but it also provides the main drainage outlet for the Northern Suburbs of Christchurch.

Streamflow in these three rivers is augmented by artificial input from domestic and commercial activities. A list of discharge consents for the Avon River appears in Appendix 2.1.

An additional drainage system - the city outfall drain - removes the water from the low lying area between the Avon and Heathcote river catchments and discharges directly into the Avon - Heathcote Estuary.

The contributing channel lengths of some urban streams change in response to the seasonal and long term fluctuations in groundwater levels. That is, with the summer decline in groundwater levels a downstream migration of stream headwaters occurs. As a result there is a seasonal fluctuation in stream baseflow.

High and rapid rises of streamflow in the urban streams are due to the efficient removal of local rainfall (usually associated with south or southwesterly weather systems) by the storm water drainage system. Heavy northwest rain along the Southern Alps causes flooding in the Waimakariri River and twice in historical times (1865 and 1868), flood waters from the Waimakariri have reached the Avon River (Reid and Dick 1960). Old Waimakariri flood channels are clearly visible on present day aerial photos, and lead into the headwaters of the South Branch, Styx, Avon, Heathcote and Halswell rivers. Following the formation of the Waimakariri Trust in 1923 an extensive system of stopbanks and groynes was constructed to contain the lower 40 km of the Waimakariri. In places the course of the River was shortened and straightened. The Waimakariri flood protection work has continued to the present day and no water has entered Christchurch since 1868.

2.1.4 HYDROGEOLOGY

Figure 2.5 is a simple physical model of the Christchurch area groundwater system that was presented by NCCB (1986). The Christchurch Regional Council is currently developing a more detailed numerical model of the Christchurch groundwater system (pers. com., David Scott C.R.C.).

Five confined gravel aquifers (Aquifer 1 the shallowest through to Aquifer 5 the deepest) have been identified in the top 250 m of the Quaternary sediments beneath Christchurch (Figure 2.2). An unconfined watertable aquifer occurs within the surface confining layer and near surface gravels. Since the gravel channels that have been mapped in the surface confining layer are considered to be present in the deeper confining layers, it is likely that there is leakage between the aquifers (NCCB 1986). The approximate western limit of the confining layers is shown in Figure 2.2. Inland of the coastal confined aquifer region the identification of discrete aquifers is difficult because it is not possible to distinguish between the glacial and interglacial gravels.

The lateral flow direction of the groundwater in the Aquifer 1 is illustrated in Figure 2.6 by the lines drawn at right angles to the contours of the aquifers piezometric surface. Although the regional lateral flow direction is from the westerly- to the easterly-quarter, on a local scale the preferred direction of flow will be controlled by the permeable gravel channels (NCCB 1986).

Measurements of standing water levels in bores of different depths show that piezometric level decreases with depth in the inland plains, and increases with depth in the coastal plains (NCCB 1986). Hence, the vertical movement of groundwater is downward in the inland plains and upward in the confined aquifers beneath Christchurch.

The vertical movement of groundwater can be illustrated by drawing a set of lines at an angle to isopiestic contours (Figure 2.7). Isopiestic contours describe the vertical hydraulic gradient of a groundwater system. If the water-bearing layers were

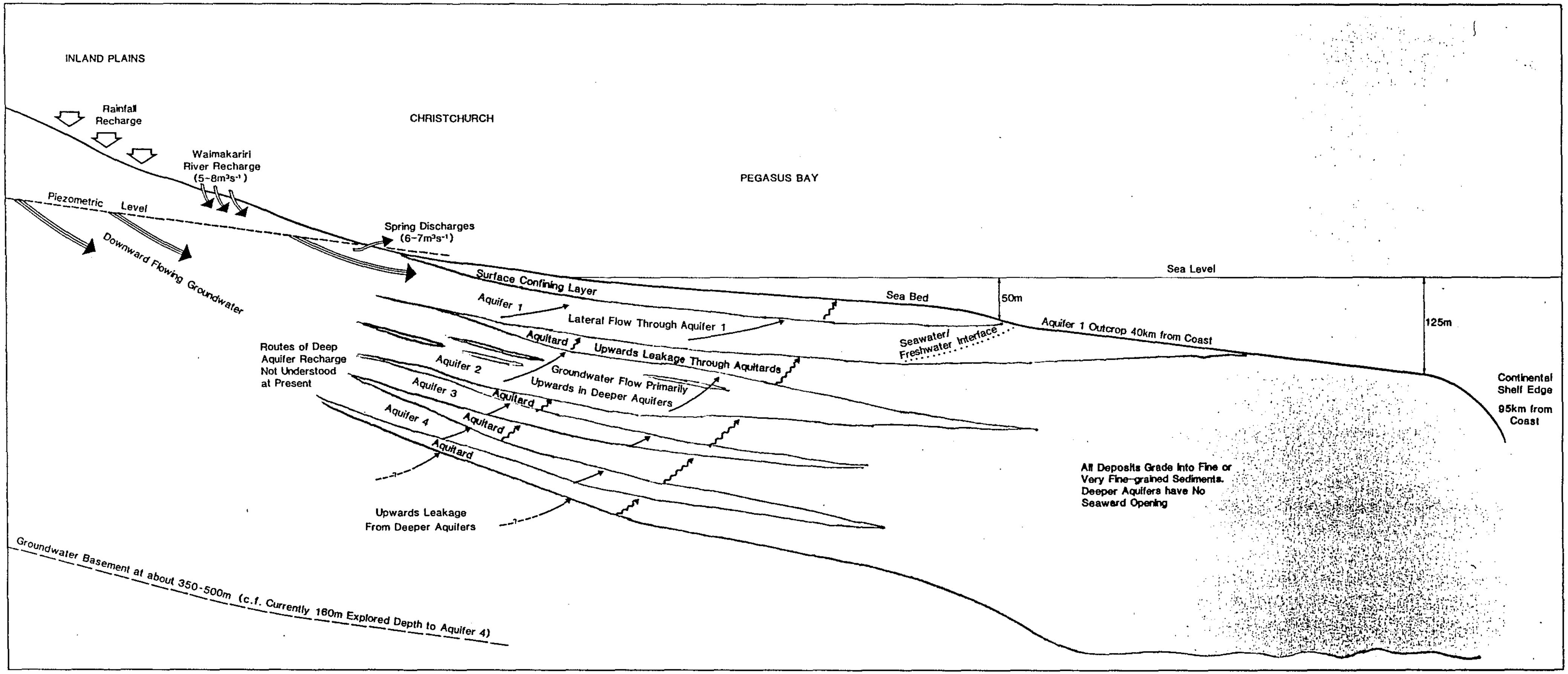


Figure 2.5 Physical Model of the Christchurch Groundwater System (NCCB 1986)

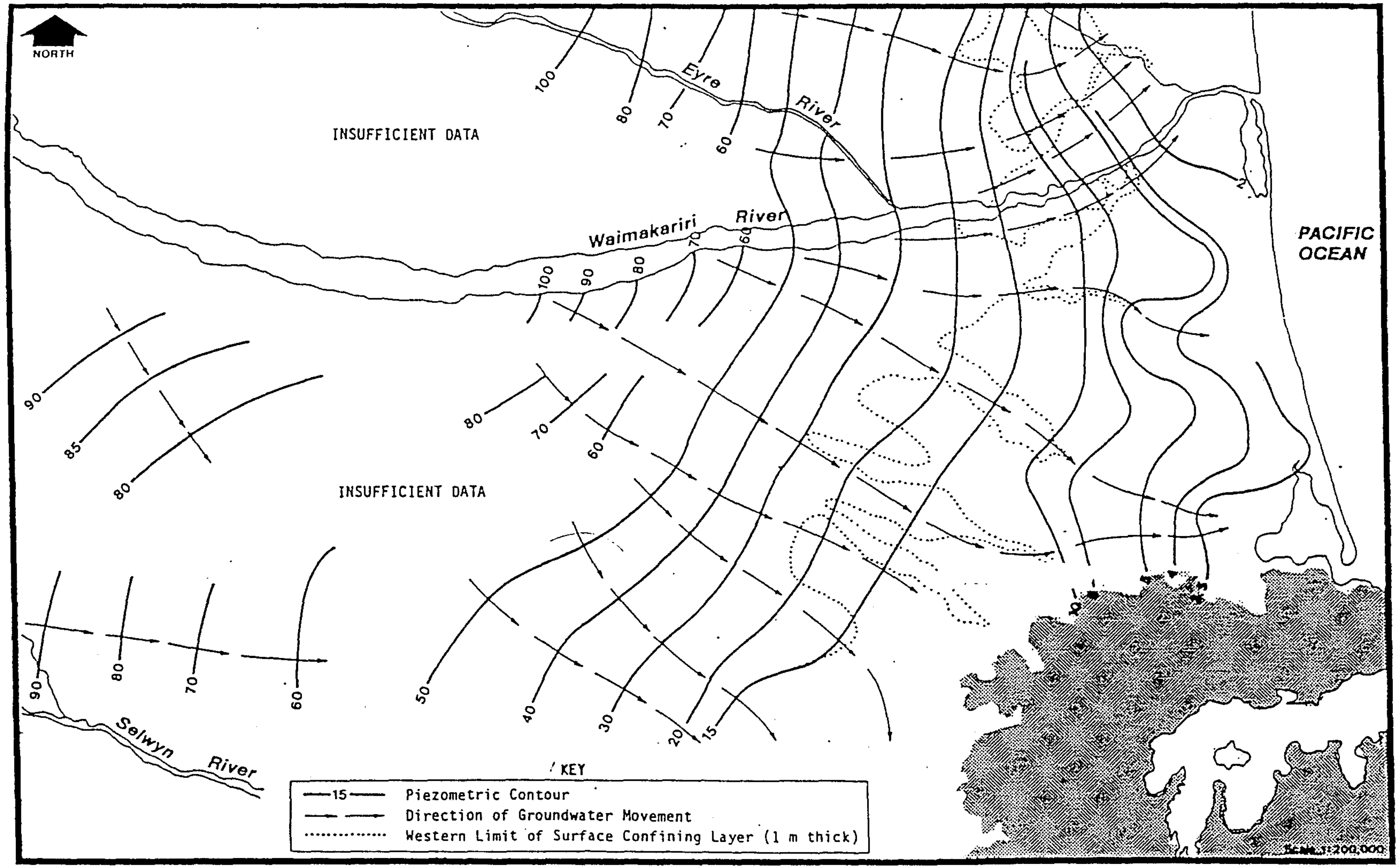
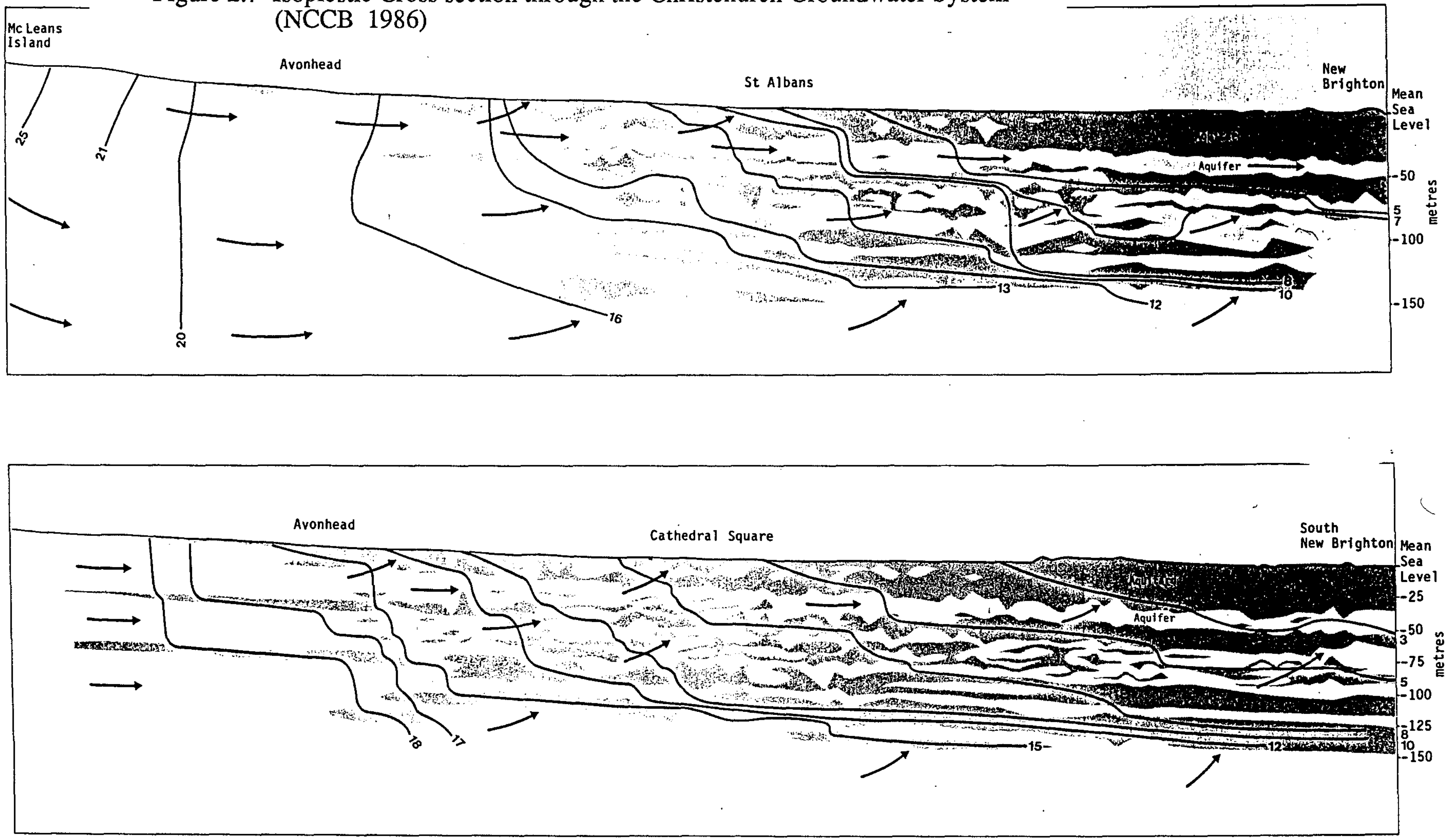


Figure 2.6 Piezometric Contour Map of Aquifer 1 (NCCB 1986)

Figure 2.7 Isopiestic Cross section through the Christchurch Groundwater System (NCCB 1986)



KEY

Fine-grained confining material

20— Isopiestic contours (pressure head in metres above mean sea level)

→ Approximate direction of groundwater flows

Figure 4.6 shows locations of west-east cross-sections

Horizontal scale

homogeneous and isotropic (i.e., lateral and vertical permeability was everywhere the same) then the set of lines would be at right angles to the isopiestic contours. However, gravels in the Canterbury plains are anisotropic with the greatest permeability parallel to the major rivers. The presence of the relatively impermeable confining layers separate the more permeable gravel layers into preferred lateral flow paths that have a large influence on the vertical direction of groundwater flow (NCCB 1986).

Outflow of groundwater from each of the aquifers beneath Christchurch is by one, or a combination, of the following mechanisms: outflow to the ocean through the seabed, springflow to the surface streams, and outflow to production and uncapped bores (NCCB 1986).

The hydrograph in Figure 2.8 is one of the longest groundwater level records in the study area. The 30 m deep bore is located at the Canterbury Museum and taps the first confined aquifer. The record shows that the average level declined by about 0.5 - 1.0 m over the period 1895 - 1905, and then remained steady (but fluctuated seasonally) through to 1992. NCCB (1986) noted, that the abstraction of water from the aquifers beneath Christchurch was occurring at an increasing rate, but the fears of over-exploitation could not be substantiated because groundwater levels had not continued to decline and had even returned to near the original levels during the wet years of the mid 1970's. However, it is considered that the natural fluctuation pattern is now greatly accentuated by the seasonal abstractive demand for public water supplies. The conclusions drawn by NCCB (1986) from the long term and seasonal trends were that current abstractions from the aquifers beneath Christchurch were having a significant effect on bore water levels resulting in a reduction in artesian free-flow, but (in 1986) the groundwater resource did not appear to be over-exploited. Annual abstraction of groundwater by the C.C.C. for the public water supply has increased from less than 1 million cubic meters in 1909 to approximately 27 million cubic meters in 1985 (NCCB 1986).

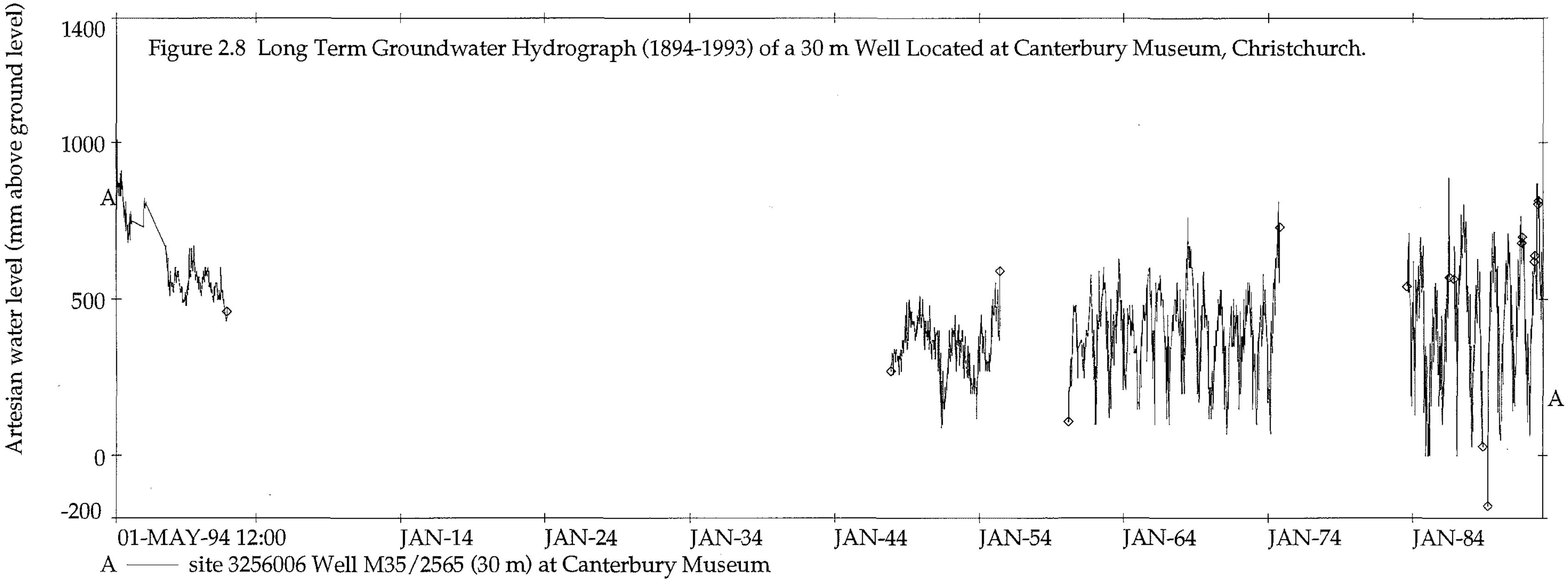


Figure 2.8 Long Term Groundwater Hydrograph (1894-1993) of a 30 m Well Located at Canterbury Museum, Christchurch.

Seasonal fluctuations in groundwater levels are about 0.7 m for each of the confined aquifers and from 5 to 10 m for the inland unconfined aquifers. McCammon (1976) found a good correlation between rainfall and confined groundwater levels, but peak levels were found to be caused by a pressure response due to increased soil moisture and not due to recharge. Weekly and daily cycles in the well hydrographs are caused by maximum daytime abstraction and lower abstraction rates in the weekends when groundwater levels are allowed to recover.

2.1.4.1 Sources of Groundwater Recharge

On the basis of geological and hydrological information three possible sources of recharge for the Christchurch groundwater system have been identified (NCCB 1986). These are:

(i) Recharge from inland deep groundwater flowing eastward and discharging at and to the east of the unconfined-confined boundary (Figure 2.2). This water may have originated as foothill runoff, plains precipitation, and/or from seepage from the Waimakariri River upstream of Halkett. This source is believed to primarily recharge the deeper aquifers beneath Christchurch.

(ii) Recharge from Waimakariri River seepage that enters groundwater in the Halkett/ McLeans Island region. The majority of this groundwater is considered to recharge the shallow groundwater that supplies the spring fed rivers. Some water may be transported to deeper levels by the downward hydraulic gradient in the inland plains and recharge the deep Christchurch aquifers.

(iii) Recharge from upward leakage from deeper to shallower aquifers. The original source of this water would have been the Waimakariri River during the deposition periods of the gravel aquifers (NCCB 1986).

In addition to the above mentioned sources, shallow groundwater is thought to be recharged from the infiltration of local rainfall and irrigation water, and by seepage from water races and irrigation channels to the west of Christchurch city. However, water race and irrigation channel water is channelled from the Waimakariri River.

2.1.3.1.1 Shallow Groundwater Recharge From The Waimakariri River

The general acceptance of a Waimakariri origin for the shallow groundwater beneath Christchurch is based on hydrological and geological parameters, and on the similarities of the chemical characteristics of Waimakariri River water to the shallow groundwater in the Christchurch area (Wilson 1976; Bowden *et al.* 1983; NCCB 1986; Taylor and Stewart 1979; Taylor *et al.* 1989). The proportion of shallow groundwater beneath Christchurch that is Waimakariri-derived has been estimated from oxygen isotope data to be in excess of 90% (Taylor *et al.* 1989).

Summary of the hydrological evidence of "Waimakariri-derived shallow groundwater"

The hydrological investigations of Waimakariri River flow loss to groundwater recharge have included analysis of gauging data that were recorded at specific locations on the Waimakariri River (e.g., Dalmer 1971, Cooper 1980, Mandel 1984, and NCCB 1986). NCCB (1986) analysed those flow gaugings which they considered to be reliable indicators of steady flow loss. They concluded that the differences in flow between the Waimakariri Gorge and Halkett Groyne (see Figure 2.3) can be largely attributed to the diversion of surface flow to underflow which remains within the river system. NCCB (1986) concluded that a reduction in Waimakariri River surface flow probably occurs between Halkett Groyne and Harewood Crossbank (averaging about 7 m /s) due to water leaving the river system and recharging the groundwater to the south, but the margins of error in the gauging data are in excess of the calculated flow loss. NCCB (1986) emphasised that more accurate gaugings were necessary to reliably ascertain flow loss.

Wilson (1973, 1976) used watertable contours near the Waimakariri to define a "recharge zone" in the stretch 33 km to 16 km from the coast as the reach of the Waimakariri River that recharges the groundwater of metropolitan Christchurch. Hydrographs of groundwater levels of wells located within the "recharge zone" show only minor fluctuations in response to Waimakariri flood events, and because of this, it is considered that floods contribute only a small portion of the total recharge. Recharge is thought to occur continuously and at a relatively steady rate (NCCB 1986). Figure 2.9 is the hydrograph from well M35/1451 located within the Waimakariri River recharge zone. NCCB (1986) considered that water levels show a lagged and damped response to river flow .

Piezometric contour maps indicate that the direction of groundwater flow in the recharge zone is towards the coastal confined aquifer region (Figure 2.6). Hydrological parameters of the near-surface aquifer suggest that groundwater which originates from Waimakariri seepage would take about one year to reach the boundary of the confined zone some 10 km away (NCCB 1986). The flow is thought to mainly occur in the near-surface permeable gravels (Callander and Broadbent 1985).

The shallow (up to 25 m deep) water-bearing gravels in the McLeans Island area that are recharged primarily by seepage from the Waimakariri River, correlate with Aquifer 1 and the near surface gravel channels contained within the surface confining layer. Some of the gravel channels that originate in the recharge zone, connect with the headwater reaches of the tributaries to the urban streams (Brown and Weeber 1992). Therefore they are believed to have important implications for the groundwater supply to these streams. When the eastward flowing groundwater meets the relatively impermeable near-surface confining layer, the water is thought to flow both under the layer into the uppermost confined aquifer, and above the layer to recharge the watertable aquifer (NCCB 1986).

<u>Summary of the hydrochemical evidence for "Waimakariri-derived shallow groundwater"</u>

Nitrate-nitrogen concentrations and oxygen and tritium isotopes analysis have been used to determine groundwater flow paths and recharge sources.

Nitrate contamination of groundwater is primarily produced by nitrate leaching within pastoral and arable cropland. Infiltration of rainfall and/or irrigation water transports

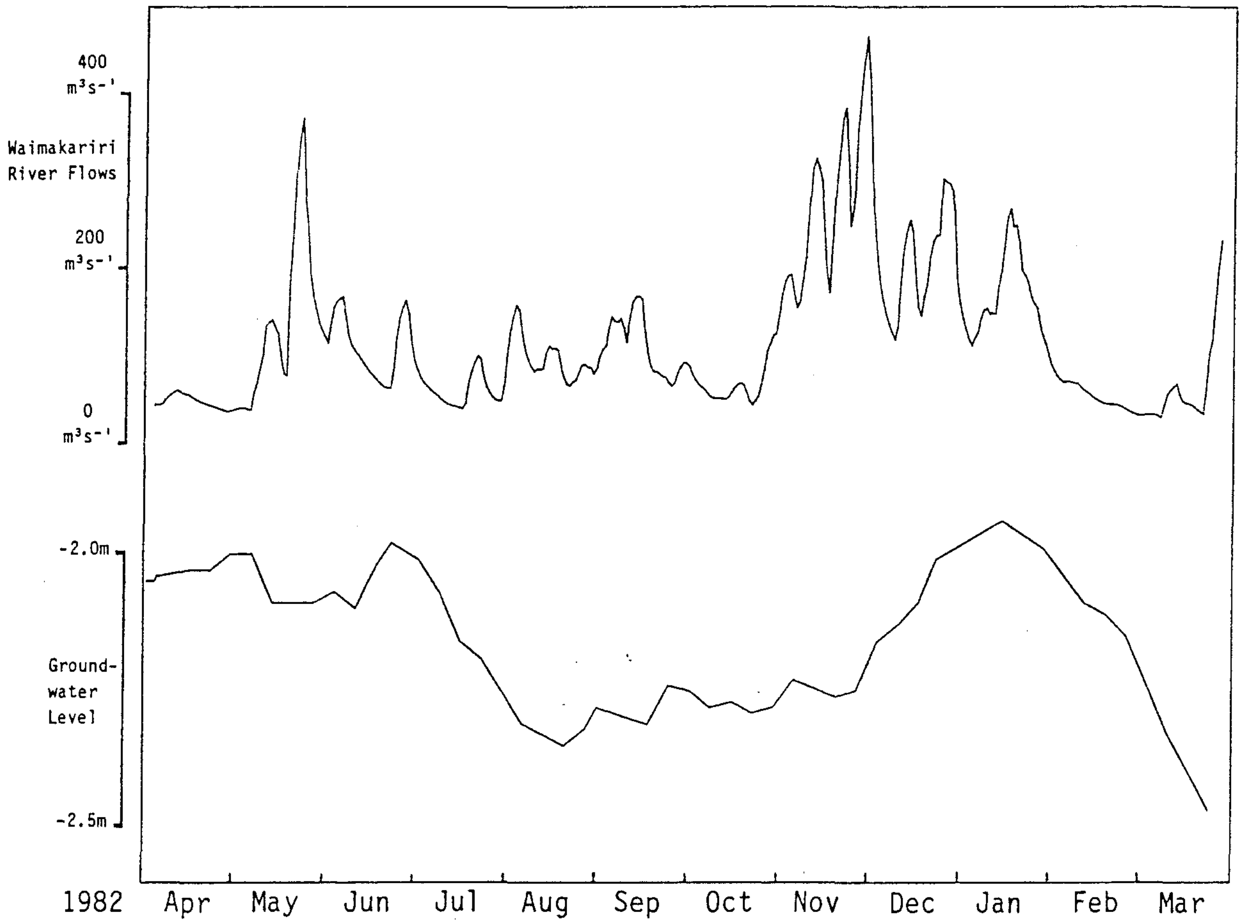


Figure 2.9 Hydrographs of bore M35/1451 compared to Waimakariri River Flow (NCCB 1986)

the nitrate to the groundwater (Burden 1984). Waimakariri River-derived groundwater is characterised by low nitrate concentrations. Chloride and nitrate-nitrogen ion concentration maps produced by Bowden *et. al.* (1983) and electrical resistivity survey interpretations by Risk (1982), generally support the location of the "recharge zone" defined by Wilson (1979). The groundwater in the "recharge zone" has low chloride and nitrate concentrations typical of the river (NCCB 1986).

Oxygen isotope measurements allow a distinction to be made between alpine-derived Waimakariri River water and local low altitude rainfall. Isotope analysis indicates that at least 90% of the water in the "recharge zone", and in the shallow groundwater beneath Christchurch, is derived from the Waimakariri River and not from direct infiltration of precipitation (Taylor and Stewart 1979; Taylor *et al.* 1989). Isotope measurements and chemical concentrations in groundwater also show that the groundwater in the triangular-shaped area with vertices at Halkett, Port Hills and Kaiapoi (Figure 2.3), is predominantly supplied by Waimakariri seepage (Taylor and Stewart 1979; Taylor *et. al.* 1989).

2.1.4.1.2 Shallow Groundwater Recharge from Deeper Aquifers

The increase in piezometric level with increased depth indicates the potential for upward leakage through the aquitards. For each of the confined aquifers this is a source of recharge from below and a corresponding loss or discharge into the aquifers above (Figure 2.7). Leakage is thought to occur through permeable flood channel gravels that are incorporated in the finer confining sediments. In addition, the fine-grained sediments that separate the gravel aquifers may not be completely impermeable throughout the aquifer system, and upward leakage may occur through some of "confining" sediments (NCCB 1986).

2.1.4.1.3 Shallow Groundwater Recharge from the Infiltration of Rainfall

Within the triangular-shaped area that contains Waimakariri-derived groundwater, a component of rainfall percolates to groundwater. The slight increase in shallow groundwater chloride and nitrate-nitrogen concentrations that occurs towards the coast reflects the influence of surface infiltration (NCCB 1986). In contrast, nitrate-nitrogen concentrations and oxygen isotope values of groundwater to the southwest of Christchurch indicate a significant contribution from local precipitation (Taylors 1989 *et. al.*). Rain falling on the inland plains recharges the groundwater system usually only during the winter months. In the summer months the soil moisture deficit results in minimal groundwater recharge from rainfall infiltration.

2.1.4.2 Overview of the Groundwater Supply to The Avon River

The Avon River derives its baseflow from the watertable aquifer and the upper most confined aquifer of the Riccarton Gravels (Aquifer 1). In the northwestern area of the catchment, where the confining layer is thinnest, the groundwater enters the river by artesian springs. In those headwater localities where the Avon River systems stream channels intersects near surface gravels, stream flow begins by groundwater seepage through streambed gravels. In historical times springs were known to have occurred further east in Lower Riccarton on Deans Ave, and within Hagley Park, but spring occurrence and flow has decreased due to the drainage of Christchurch, increased groundwater abstraction and the construction of impermeable surfaces that inhibits the infiltration of local rainfall. The location of Deans Avenue and Hagley Park are shown later in this thesis in Figure 3.1. A seasonal fluctuation in spring contribution to the Avon River occurs due to the summer decline in groundwater levels caused by abstraction, lower summer rainfall and increased evapotranspiration.

2.1.5 STREAMBED COMPOSITION

In 1980, the Christchurch Drainage Board (CDB) published a report on the biological aspects of the Christchurch urban rivers. Included in this report is an investigation of streambed composition. A summary of their results is shown in Table 2.1.

The physical composition of a stream bed is closely related to the geology and geography of the local catchment. The composition of the stream bed in the Christchurch urban streams reflects this relationship. The Heathcote River, which is nearly one-third hill catchment covered by loess deposits, is very different from both t

Table 2.1 A summary of sediment compositions in the Avon, Heathcote and Styx River Catchments (CDB 1980)

	Avon		Heathcote		Styx	
	Range	Median	Range	Median	Range	Median
(I) Non Tidal Reaches:						
Silt/ Clay	0.15 - 50.21	4.38	0.36 - 86.70	18.20	0.0 - 74.79	8.72
Sand	0.08 - 92.20	36.43	4.06 - 91.60	47.02	1.74 - 96.31	55.27
Gravel/ Pebble	2.98 - 99.77	58.26	0.10 - 92.56	5.11	0.0 - 98.17	7.10
Fine Sand	0.03 - 75.61	17.57	0.72 - 78.00	29.88	0.52 - 82.11	31.08
Medium Sand	0.03 - 37.06	8.14	0.30 - 44.56	8.38	0.16 - 54.84	6.45
Coarse Sand	0.0 - 10.68	2.67	0.40 - 11.50	2.96	0.08 - 17.35	2.60
(II) Tidal Reaches:						
Silt/ Clay	4.03 - 93.51	31.79	28.47 - 99.05	72.49	2.36 - 92.97	44.09
Sand	1.43 - 94.80	66.16	0.95 - 71.29	21.82	7.03 - 95.16	55.91
Gravel/ Pebble	0.0 - 25.14	0.15	0.0 - 29.80	0.0	0.0 - 15.97	0.0
Fine Sand	0.30 - 88.66	55.85	0.71 - 69.68	15.53	5.64 - 69.55	38.19
Medium Sand	0.39 - 52.01	5.23	0.10 - 25.11	2.30	0.45 - 53.31	8.87
Coarse Sand	0.0 - 4.39	0.32	0.0 - 7.09	0.25	0.0 - 40.48	1.07

Avon and Styx, which have flat alluvial plain catchments (CDB 1980). The Heathcote River throughout its course has a higher mean proportion of the fine clay/silt size sediment than either the Avon or Styx Rivers.

High proportions of the gravel-pebble component found in the non-tidal reaches of the streams generally corresponds to the mapped position of Waimakariri flood channel gravels in NCCB (1986). Sediments in the tidal-influenced section of all three streams are dominated by fine and medium grained sand, and the silt clay sediments.

2.1.6 CHRISTCHURCH CLIMATE

The climate of Christchurch is largely influenced by the presence of the Southern Alps, Banks Peninsula and proximity to the Pacific Ocean. The prevailing wind directions are east-northeasterly and from the southwesterly quarter. The Southern Alps act as a massive barrier to the westerly airstreams and produce the föhn northwesterly winds. Although northwesterly winds only blow about 3% of the time, they are an important factor in the Christchurch climate and are responsible for most of its highest temperatures. A predominance of northeastly winds occur in the summer due to the differential heating of the Canterbury Plains and the Pacific Ocean (McGann 1983).

Average rainfall in the Christchurch area varies between 600 and 700 mm (Figure 2.10), which is relatively low compared to other parts of the country. Wide variation can occur from month to month and year to year. Rainfall is fairly evenly distributed about the year with a tendency for a winter maximum (Durant 1979). Nearly half of the mean annual rainfall occurs with winds from the southwest and three-quarters of the rainfall with winds between the south and west. As a result of the rainshadow effect of Banks Peninsula, the northern parts of Christchurch have a slightly lower mean annual rainfall than the southern parts (Figure 2.10). High intensity, short duration rainfall is usually associated with thunderstorm activity and is not very common in Christchurch.

Details from three meteorological sites, Christchurch Airport, Wigram Airport and Botanical Gardens, appear in Appendix 2.2. The location of these sites are shown in

Figure 2.10 Mean Annual Rainfall in the Banks Peninsula and Adjacent Plains Area (after Jayet 1986)

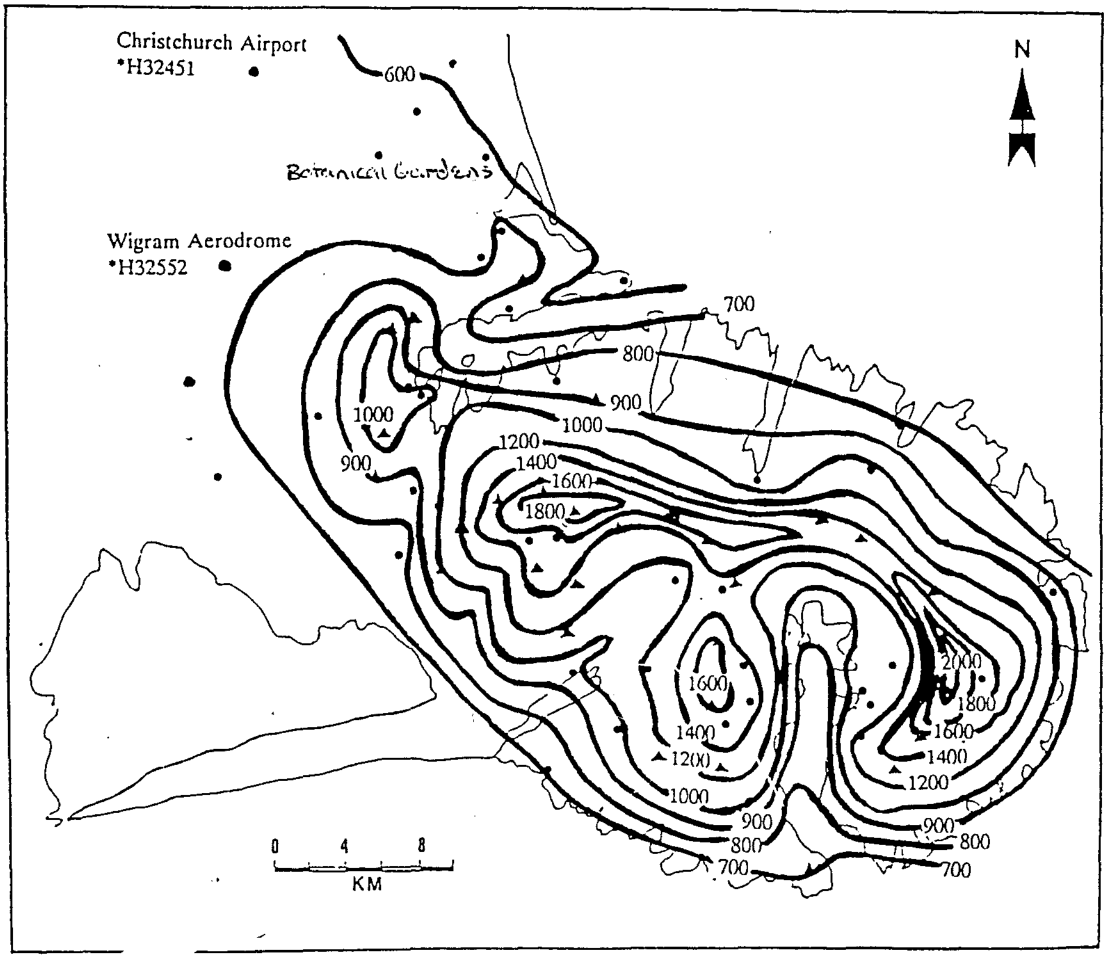


Figure 2.10. The Christchurch and Wigram Airport sites are located at the northwest and southwest margins of the Avon River catchment, respectively. The Botanical Gardens sites occurs within the catchment. The variation in mean annual total rainfall between the three site is 18 mm (648 mm for both Christchurch and Wigram Airports and 666 mm for the Botanical Gardens).

Total annual pan evaporation is 1271 to 1329 mm and a serious moisture deficit frequently occurs during the summer months. Droughts in Christchurch arise from the persistent presence of anticyclones and westerly or northwesterly wind (Trewinnard and Tomlinson 1986). Since records began in 1894, there have been 25 occasions when 30 or more consecutive days have had less than 1mm of rain. The period from November 1981 to August 1982 was the driest for the ten-month period November to August since records began in 1894. A total of 306 mm of rain was recorded, which is only 54 % of the average of 566 mm. The very low rainfall was accompanied during the summer and autumn by very high evaporation, which accentuated the drought conditions then prevailing in Canterbury (McGann 1983).

Mean daily air temperatures range from a winter low of 5 to 6°C to a summer high of 16.5 to 17°C. Midsummer day length is approximately 15.5 hours and the mid winter day length is 9 hours. Frosts are common from May until September, with an annual average of 86 days with frost for the three meteorological sites. Mean ground temperatures range from -1 to -2°C in the winter to 8 to 10°C in the summer.

2.1.7 SOILS

Most of the soils to the west of Christchurch have low water holding capacities and are very free draining; there is seldom any surface runoff. They overly unconfined aquifers into which soil water surpluses drain. In contrast, the soils of urban Christchurch have high water holding capacities. These are deep soils and because the water table has been artificially lowered by drainage, most are moderately free draining. In some localities the presence of underlying fine sediments prevents the drainage of water to

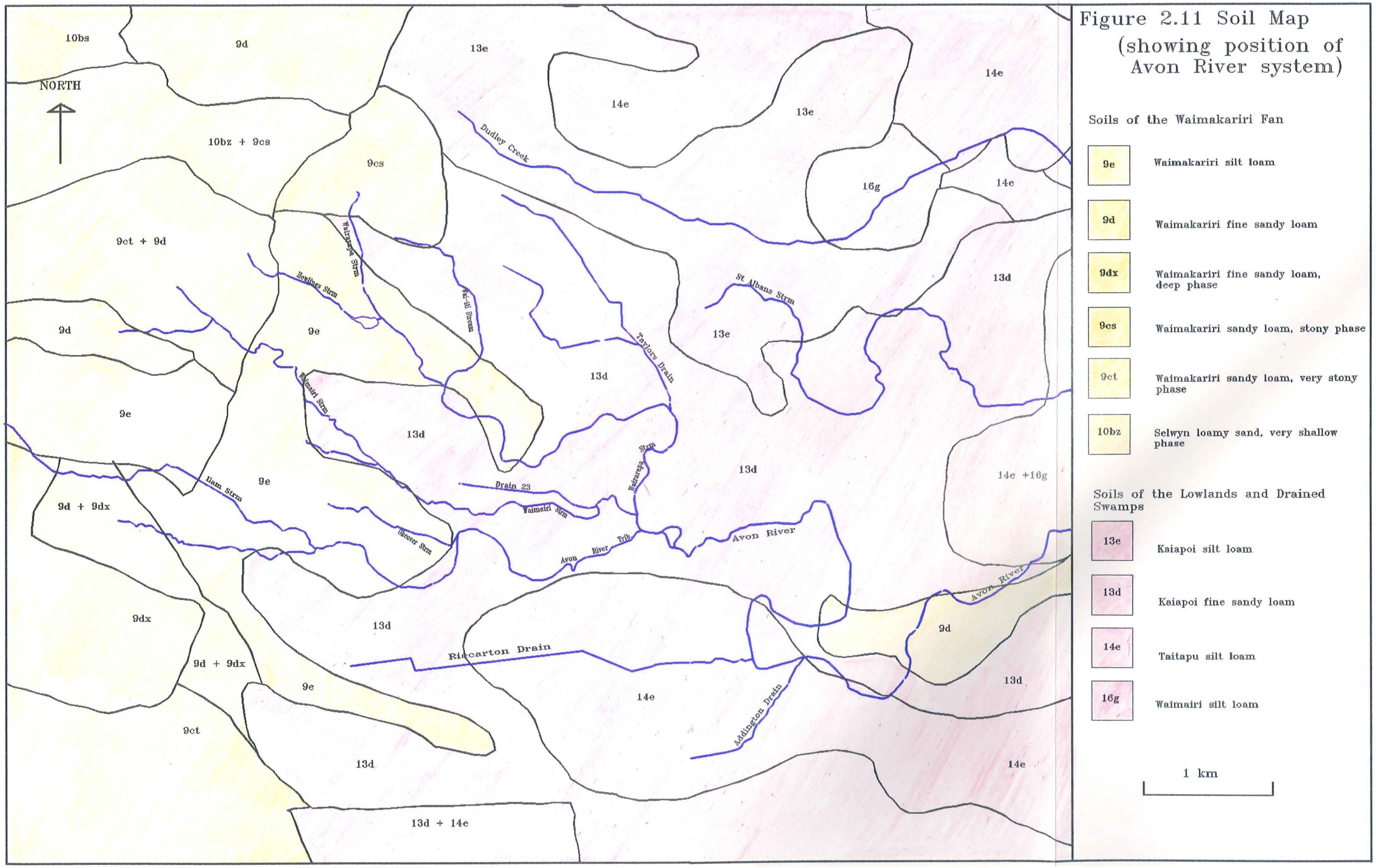


Figure 2.11 Soil Map (showing position of Avon River system)

the groundwater aquifers. Where the infiltration rate of the soil is exceeded or the soil is saturated, surface ponding or runoff into depressions and urban streams occurs.

The soils of the Christchurch area have been placed into four groups (Raeside and Rennie 1974). Figure 2.11 shows the soils as they occur in the study area.

(i) Port Hills soils: These do not appear in the Avon River Catchment.

(ii) Waimakariri Fan soil: These soils are highly variable and occur on stony greywacke alluvium which the Waimakariri deposited during relatively recent floods. The soils are very free draining. Towards Christchurch, sediments of fine texture overlie the coarser alluvium, and merge into the fine textured, poorly drained alluvium of the lowland. The soils of this group that occur within the catchment of the Avon River are:

a) Waimakariri fine sandy loam (shallow phase). This soil occurs in the vicinity of the Avon River stream channel between Hagley Park and the Dudley Creek confluence.

b) Waimakariri silt loam (9e). Most commonly deposited in the lower reaches of the Waimakariri River where stream velocity decreases. It is medium draining and occurs on the western margins of the Avon River catchment.

(iii) Lowland and Drained Swamp Land: These soils were subject to a permanent or periodic high water-table in their natural state. Most of this land has been drained and is not now subject to the problems of high water tables. However, in some places during the winter the water table rises to within 1 m of the surface and the soils are very wet or water logged. In summer, the soils remain moist as the watertable does not fall much below 1 to 2 meters of the surface. The soils of this group that occur within the catchment of the Avon River are:

a) The Kaiapoi fine sandy loam (13d). This is the most common soil in the study area and occurs in the lower reaches of the Avon River tributaries.

b) Kaiapoi silt loam (13e) is relatively free draining, but is in areas of high watertable. Only occurs in the vicinity of Taylors Drain.

c) Taitapu silt loam (14e). Occurs along the southern edge of the Avon River catchment study area. The Taitapu Series are located in the former swamps of the lowland fringe. They are developed on fine alluvial silts deposited on marine sediments. The majority have slow or very slow through drainage.

(iv) Sand Dune Soils: These soils occur beyond the study area in the eastern section of the Avon River catchment adjacent to estuary and coast.

2.1.8 LAND USE

In 1981, the population of Christchurch was 289 959 (1981 census records). Figure 2.12 shows the expansion of Christchurch since 1886. The land uses that made up the Christchurch urban area in 1976 are listed in Table 2.2.

On the outskirts of the urban area the soil type greatly influences farming intensity. To the north of Christchurch farming is predominantly orchard, berry fruit and dairying. To the west of the city the better soil types are used for intensive cropping, but a large proportion of the area supports horse training establishments and small lifestyle farmlets. The low water holding capacity stony soils in the McLeans Island area are very drought prone and are used for low intensity grazing. High summer temperatures and long daylight hours mean that for optimal growth, plants require twice as much water as is available from the natural rainfall; hence summer irrigation rates are high.

Much of the land within the western and northern areas of the Avon River catchment is zoned residential. The area is composed of a relatively large amount of unpaved ground, occurring as parks, reserves, schools, golf courses and the University of Canterbury. To the southeast, the Avon River drains the central city and part of the industrial area of Addington.

Figure 2.12 Christchurch Urban Expansion since 1886 (NCCB 1986)

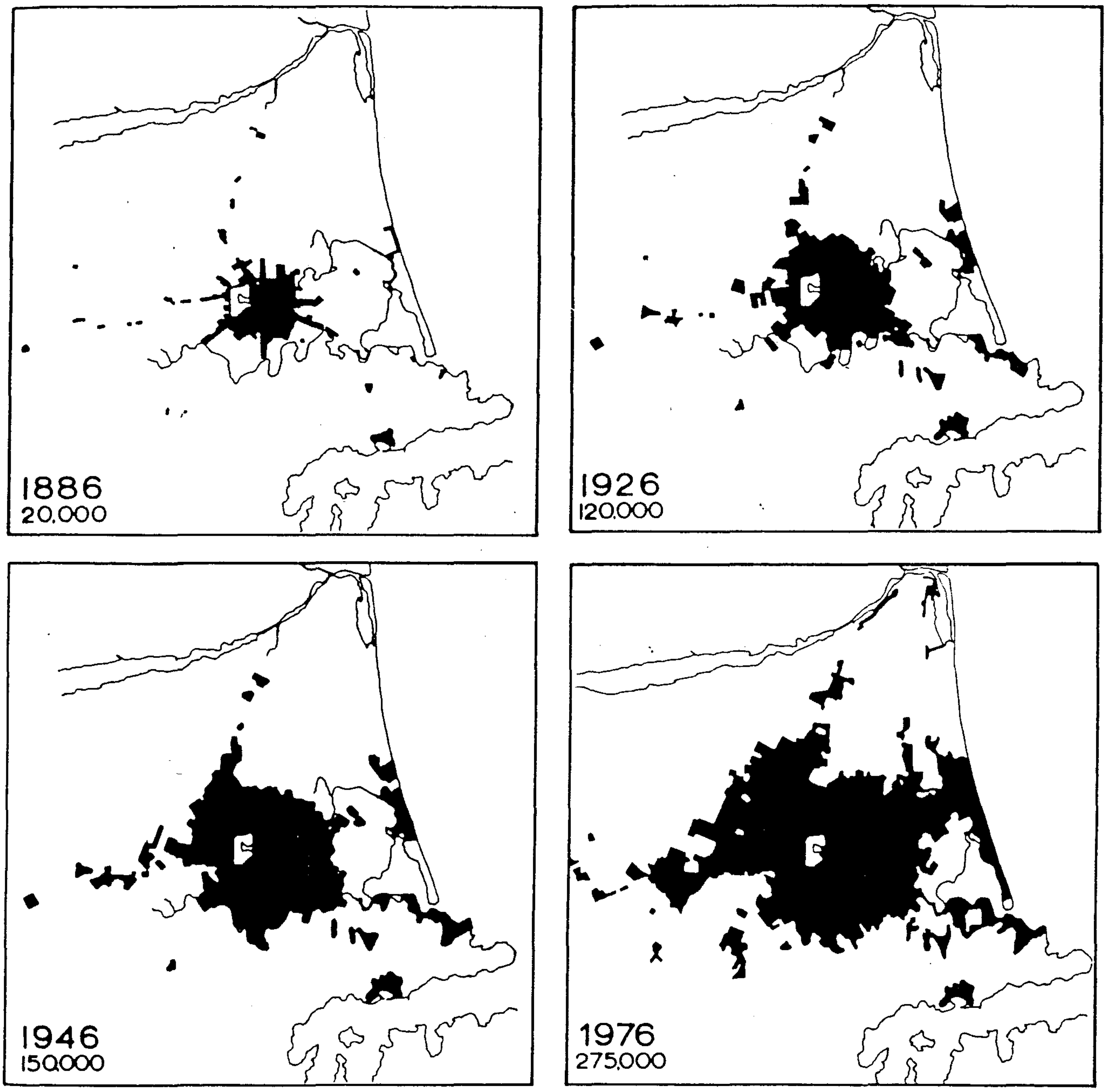


Table 2.2 Land use in the Christchurch Urban Area in 1976
(after NCCB 1986)

Land Use	Area (ha)	% of Total
Housing	6208	44.4
Industrial	668	4.8
Commercial	299	2.1
Central Business District	109	0.8
Public Uses and Utilities	979	7
Open Spaces	1097	7.8
Roads	2064	14.8
Agricultural and Vacant	2553	18.3
Total	13977	100

2.2 HISTORICAL DEVELOPMENT OF THE AVON RIVER SYSTEM

In section 2.2, some of the places and streets mentioned in the text do not appear on a location diagram in this thesis. A street map of Christchurch will aid understanding if the reader is not familiar with the Christchurch area.

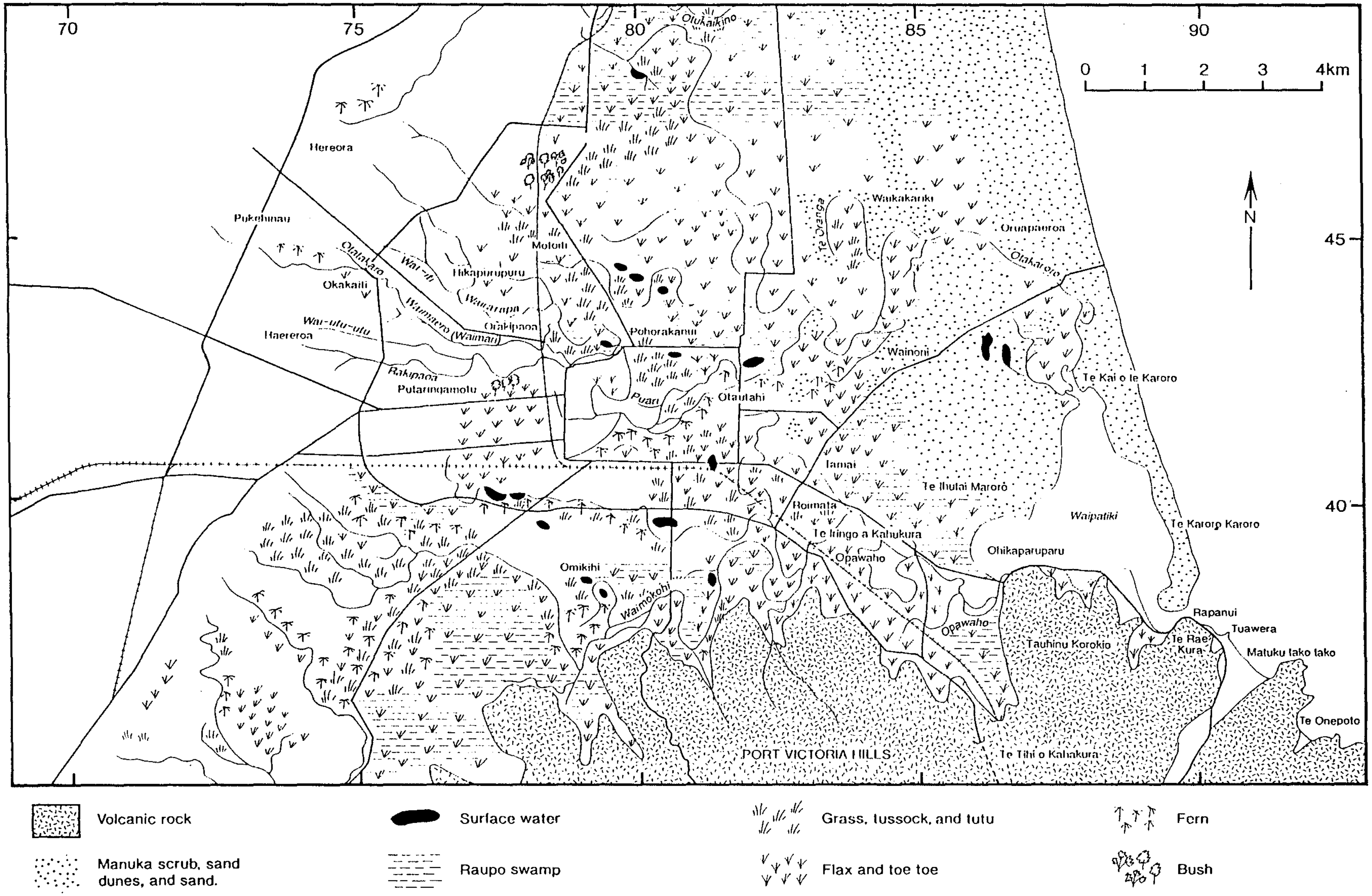
2.2.1 PRE-EUROPEAN HISTORY OF THE CHRISTCHURCH AREA

Pre-Polynesian Canterbury (<1000 AD) was forest mantled mixed podocarp and Kanuka dominated tracts. Natural and human induced burnoffs altered the landscape to one dominated by large raupo swamps interspersed between sand-dune ridges and lobes of the Waimakariri alluvial fan. The sand dunes occurred in rows along the coast with older inland dune complexes covered with grasses and manuka (Scott 1963). The swampy areas were vegetated with rushes, flaxes and ferns. Open areas of grasslands were interspersed between the swamps and sand hills. The Avon and Heathcote Rivers served as the main drainage channels to the estuary and their baseflow was derived from natural spring flow and drainage of swamps (Figure 2.13). The drainage pattern is considerably different to that of the modified present day drainage system.

Travis Swamp at Burwood was a former estuary of the Avon River. Radiocarbon dating of estuarine shells places the maximum age for the change from estuary to swamp, at 1630 ± 50 years B.P. (Deely 1991). Blake (1967) suggests that at one time the Avon River may have been a distributary of the Waimakariri River, and the associated larger flows caused it to discharge into the sea in the vicinity of Travis Swamp.

The Canterbury area was first settled around 800 years ago by the Maori. There were Maori settlements on the sand hills adjacent to Moa Bone Point Cave, at Bromley, and on the northern Banks of the Avon River (Penny 1982). By about 500 years B.P., thousands of hectares of native bush had been burnt off in the Canterbury area and the subsequent cover was scrubby vegetation such as bracken and grass (McFadgen 1989).

Figure 2.13 Map of Christchurch Area in 1856, showing Waterways, Swamps, and Vegetation Cover (compiled by K. Sibley, Christchurch Drainage Board)



The deforestation reduced the natural resources of the area considerably and the Maori were forced to change their hunter-gather lifestyle.

The Maori established a number of small settlements inland and utilised the Avon River to transport cargo upstream to "the bricks", which was as far upstream as their small boats could navigate. These people were known as the *O-roto-repo* "the swamp people". They named many of the streams and springs in the Christchurch area. The Avon River (below Monavale) was known as *Otakaraoro* "a place of games" or *Orotere* "swamp". The Avon River Tributary (above Mona Vale) was known as *Rakipaoa* "smoky sky" and its headwater springs in Avonhead were the *Haereroa* "long wanderer". *Wai-utu-utu* " lifted up water" has been renamed Ilam Stream. The Wairarapa and Wai-iti streams have retained their names and translate as "glistening water" and "little stream" respectively. The swamp in upper Fendalton, where the Wairarapa Stream originated was *Hika-puru--puru* "falling hair". The Waimairi Stream was known as *Waimaero* "little water" and the springs that formed its source *Ohakaiti* "named after a man". In a section of the*Waimaero*, known as*Wai-iri-iri*, the spring water was considered to be of such quality that it was reserved for healing purposes (Tua *et al.* 1990; Taylor 1950). When the first European settlers arrived in 1840's, the Maori population was between 400-500.

2.2.2 OUTLINE OF THE HISTORY OF DRAINAGE OF THE CHRISTCHURCH AREA

In 1849, Captain Thomas chose Christchurch as the site for a settlement proposed by the Canterbury Association. The Avon River not only solved the immediate problem of a pure water supply but it was also utilised as a canal (Hercus 1948). In selecting the site of Christchurch, Captain Thomas' first concern was apparently not with the problem of the future drainage of the area. The site was low lying and flat with the city centre only 5 m above sea level. Initially the natural drainage system provided by the Avon and Heathcote rivers was utilised. To make some areas inhabitable a large amount of work had to be undertaken in order to lower the water table. In 1858 two stormwater drains were built; one discharged into the Avon River via Fitzgerald

Avenue, and the other into the Heathcote River via Heathcote Road and Radley Street. Because the site was low lying, depressions between sand dunes were often lower than the rivers that drained the area so that when drains were built they had to follow circuitous routes to achieve an outfall. In 1867, most of the major swamps were still undrained (for example, Halswell, Hagley Park, Papanui).

In addition to the problem of removal of superfluous quantities of subsoil water, was the disposal of sewage. The early settlers made no attempt to deal with the sanitation problems and as a result, the Avon and Heathcote rivers, as well as many of the swamp areas, became polluted. Up until 1884, the Avon River received sewage discharge from the hospital and there were constant complaints being made to the authorities about the foul state of the city rivers. In 1874, Christchurch had the highest number of deaths per population of any New Zealand centre. A major contributing factor to the high death rate was water borne diseases such as typhoid, diptheria and dysentry (Hercus 1948).

In 1875, only twenty years after Christchurch was first settled by Europeans, the Avon River and most of the natural surface water had become so seriously polluted that an Act of Parliament was prepared to provide for the drainage of Christchurch (Wilson 1989). In 1875, the Christchurch Drainage Board was created and charged with this responsibility. In 1877, the Board commissioned William Clark, a British drainage engineer, to develop a drainage scheme. The key points of the scheme that Clark presented to the Board were: that rain water should be carried by street surface channels and pipe drains to existing creeks and rivers, some of which would require modification to improve drainage; sewage was to be carried in a separate system of sewers ranging from nine inch pipes at the extremities to a main sewer 5 feet in diameter ; drainage of swampy areas was to be achieved by deepening of existing drains and the cutting of new drains where necessary (Wilson 1989). Between 1878 and 1880 the Christchurch Drainage Board constructed seven large stormwater drains to the Avon and Heathcote rivers, and made improvements to existing drains. By 1885 most of the low lying areas of Christchurch were no longer water logged (Wilson 1989). In 1882, the sewage farm at Bromley was completed. During the 1880's and 1890's New Zealand suffered a financial depression and minimal drainage work was undertaken in this period. Many roads were left undrained and the Richmond and St. Martins area were still largely swamp.

In the early 1900's sewers and storm water drains were extended to the outer suburbs and streams and drains were deepened and cleared. Additional drains were built in areas not previously drained (such as Fendalton, Bryndwr, Northcote and Riccarton). Between 1925 and the early 1930's the drained and sewered areas of Christchurch were more than tripled. Throughout the rest of the 1930's, 40's, 50's and 60's drains and sewers were extended and maintained as necessary (Hercus 1948; Wilson 1989).

2.2.3 HISTORY OF THE AVON RIVER

One of the earliest documented European references to the Avon River was in 1844 when John Deans, in a letter to his brother, wrote "The place where I have squatted (now known as Riccarton) has many advantages; and a river of water clearer than crystal (indeed the finest water I ever saw) running past the front." (Deans 1937). The Deans Brothers named the Avon after a river near their Ayrshire home. The Avon was initially known as the Shakespeare, but was changed at the Deans' request (Rickard 1968). 'Avon' is a Celtic word meaning 'river'.

In the early days of settlement the river was utilised as a canal with schooners carrying freight up as far as the Barbados Street bridge and a 14 m long passenger steamer called the "Diamond" ferried passengers from the Colombo Street bridge to New Brighton (Morrison 1948, Deely 1991). However, Deans in the 1840's had introduced watercress into the river, and by the 1880's the watercress had spread and was trapping debris causing the river to silt up. The construction of the Horners Stormwater Drain in the late 1870's caused the river catchment to be reduced by 16.2 km^2 by diverting some of the natural watershed to the Styx River. The flushing of the tributaries by heavy rain caused an enormous amount of sediment to enter the Avon River and the sediment was becoming trapped in the streambed vegetation. The stream dredge "Avonia" was used by the Christchurch Drainage Board between 1894 and 1899 to remove weed from the Avon River throughout the city area. This proved successful in clearing weeds and sediment from the city area, but caused the river to become blocked below Fitzgerald Avenue. In the early 1900's the river was only 3-4 inches deep in places where it had previously been 10 to 20 feet. At this time a general economic depression was occurring in New Zealand and no improvements were made to alleviate the sedimentation problem. In 1927, the Christchurch Drainage Board began removing the sediment from the river with a river sweeper. It took the river sweeper approximately three years to clear the section of river between Carlton Bridge and 1 km upstream of the estuary (Lamb 1981). In the 1940's and 50's, the Christchurch Drainage Board used a drag line for clearing the river and after 1950 the sediment was removed onto adjacent land (Deely 1991). The river has been maintained as necessary since the 1950's , but the historical decline in baseflow stopped the river returning to the depth it had in the 1800's.

In 1948 the decline in baseflow levels of the Christchurch urban streams was apparent. Hercus (1948) wrote about the Avon and Heathcote rivers, "Today (1948) the situation has been modified by the construction of artificial drains which has diminished the amount of water that would discharge into these rivers and they have as a consequence fallen below their original level."

The development of the Christchurch drainage system has changed the flow characteristics of the Avon River. Where inconveniently located flowing springs occurred, the water was channelled to the nearest stream. The progressive lowering of the watertable and drainage of swamps caused a reduction in the source of the Avon River baseflow. The limited amount of historical low flow data makes quantitative assessment of the trend in Avon River baseflow since European settlement impossible. Anecdotal information and recorded historical observations both confirm that springs that used to flow, now either do not flow, flow only during periods of high groundwater

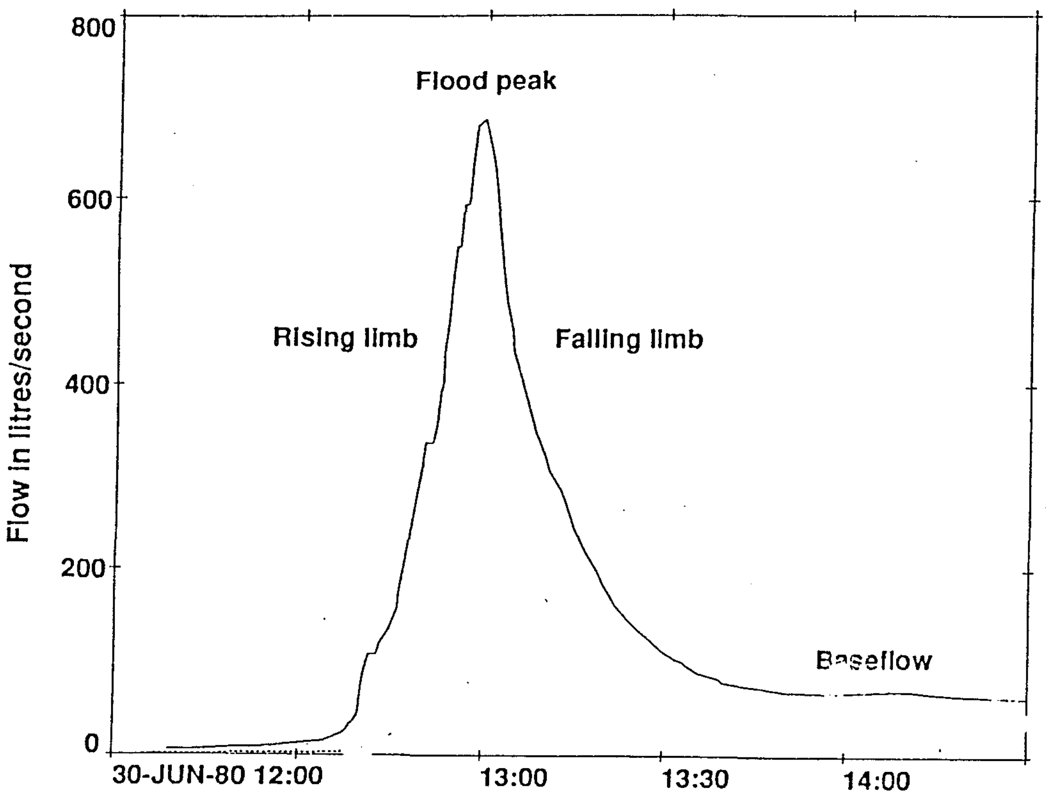


Figure 2.14 Flood Hydrograph (Duncan 1992)

levels, or no longer exist because they have been buried. The latter may still contribute to streamflow where they have been piped to the stream channel prior to burial.

To get some idea of the scale that the water table was lowered, in Lincoln Road, a drainage pipe was installed to remove the large quantity of sub-soil water and allow a sewer drain to be installed. The drainage pipe lowered the water-table level in the area by in excess of 3 m (Engineers Annual Report to the Board, 1884; Hercus 1948).

2.3 AVON RIVER FLOW REGIME

The flow regime of a river is the unique way in which its flow changes from day to day, season to season and from one year to another. Regime defines the character of a river, how liable it is to flood or to experience long periods of low flow. Two components of river flow can be identified from a flow hydrograph: baseflow and flood flows. The baseflow of a river is derived from the seepage of groundwater into the channel or from outflow from surface water storage (e.g., lakes, swamps). Hydrographs of floods commonly show the rise of flood waters (termed the "rising limb") and their recession ("falling limb") (Figure 2.14). In hydrograph analysis, baseflow and flood flow are separated by drawing a line from the start of the rising limb of the flood to a point on the falling limb. The base flow separation technique used in this study is explained in Section 3.4.2. The slopes of the rising and falling limbs reflect the nature of the rainfall event that caused the flood, the hydraulic parameters of the stream and runoff characteristics of the catchment.

2.3.1 FLOOD FLOW

A flood hydrograph of the Avon River at Gloucester Street is shown in Appendix 2.3. The flood hydrograph shows a characteristic response of an urban stream. That is, a short lag time, with steep rising and recession limbs and little or no increase in baseflow. Anecdotal information from riverside residents in the upper Avon catchment suggests that the frequency with which bankspill occurs during storm runoff has drastically increased with the progressive development of Christchurch (Mrs Moros, 59 GREERS

Table 2.3 Mean monthly Avon River Baseflow from 1980 to 1993												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Mean**
1545	1451	1445	1447	1563	1620	1725	1847	2011	1968	1945	1767	1697

Road; Mr Moore, 7 Royds Street). Mrs Moros estimated that 35 years ago her property would flood once or twice every ten years, now it would do so once or twice every year.

2.3.2 BASEFLOW

Seasonal variations in Avon River baseflow occur in response to seasonal groundwater level fluctuations. Mean monthly baseflows increase from April to September and decrease from October to March (Table 2.3). The seasonal fluctuation in baseflow is also reflected by the migration of headwater spring positions in some tributary streams. During the winter when groundwater levels are high, the headwater spring positions occur upstream of their summer position. In all of the Avon River tributaries streamflow was found to increase downstream.

2.4 HYDROLOGICAL EFFECTS OF URBANISATION

Urbanisation causes extensive modifications to the land surface, an increase in the degree of imperviousness and changes in discharge characteristics. The hydrologic impact of these developments can include changes in the volume of storm and annual flow, peak discharge, time of concentration of direct runoff, surface drainage patterns, groundwater recharge from precipitation, total annual rainfall and distribution, sanitary and chemical quality of water, sediment production, and an increase in water use with the increase in population (McPherson 1974). These changes can combine to produce a complex modification to the hydrological water balance of an area.

The construction of hydraulically efficient stormwater drainage systems and impervious surfaces, facilitate the rapid removal of surface water, causing an increase in the volume of storm flow and higher peak discharges and a reduction in the time to flood peak (i.e., steepening of the rising limb; e.g., Figure 2.16) (McConchie 1990; McPherson 1974). Since the runoff is removed quickly from the catchment at the end of the rainfall event, the recession limb is also steepened. The drainage of swamps, which act as ponds to slow down runoff, increases the height of a flood peak. The number of floods per year, particularly small floods, increases. The effect of

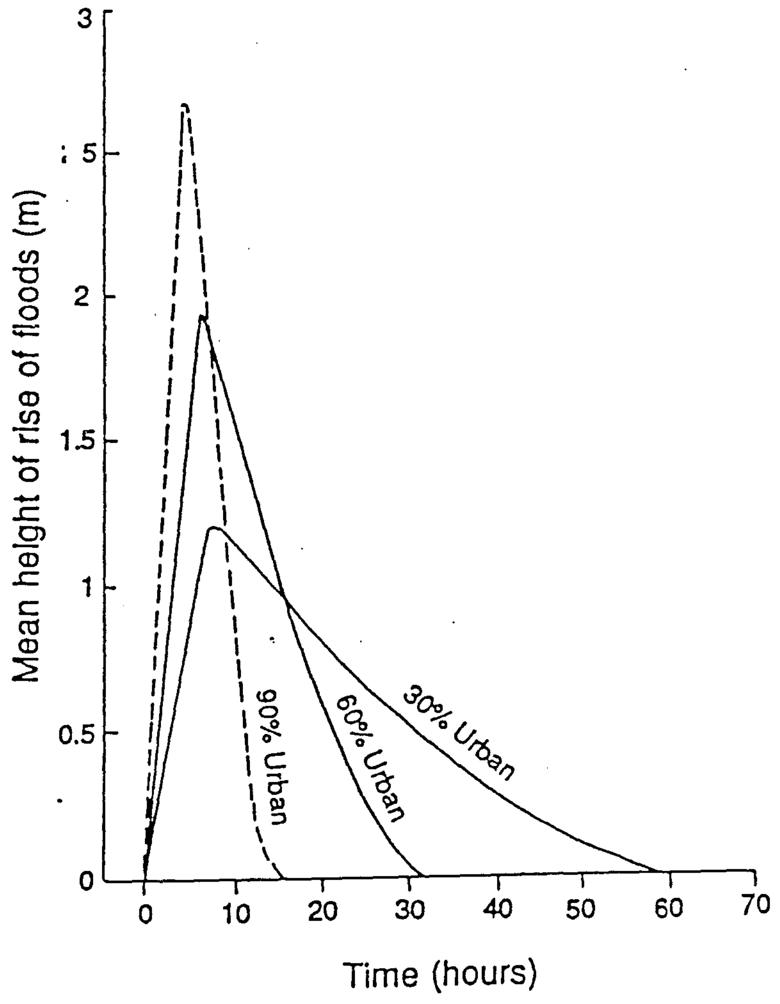


Figure 2.15 Flood Hydrograph Response to Urban Development

urbanisation on larger floods is usually less because during large storms most of the catchment will become saturated, and since the water cannot infiltrate the surface it will behave as if the surface had been "sealed".

The increase in the impervious area tends to reduce the volumes of infiltration and evapotranspiration of a catchment. However, local increases in evapotranspiration can occur in areas that are extensively irrigated. Local runoff can also be increased as a result of climatic modifications caused by large urban centres. All these factors collectively change the surface runoff regime, a change which is often reflected in an alteration of the amount of groundwater recharge. Over-exploitation of groundwater resources causes a progressive decline in groundwater levels.

Baseflows of streams can be diminished by the construction of impervious surfaces that facilitates a reduction in infiltration, lower rates of stream bed recharge due to declining groundwater levels, and engineered diversions of stream flow. Conversely, increases in the low flow of streams as a result of urbanisation has also occurred (Miller 1966). Under low flow conditions artificial discharge, leakage from subsurface pipes, and septic tank drainage can augment stream flow above natural flow rates. The lower rates of evapotranspiration due to increased imperviousness and the removal of vegetation has also been credited with increasing baseflow under some hydrological conditions (McPherson 1974). But most often there is a decrease in the base flow of those urban streams that do not receive artificial input.

2.4.1 WATER POLLUTION

A natural function of streams is to assimilate the waste materials that are washed from the land. In urban and particularly industrial areas the waste may be so excessive and of such a nature that the life of the streams is destroyed and the streams degraded to the status of mere drains. The separate stormwater system in cities, discharge an annual load of pollution to the waterways similar to that coming from the secondary sewage effluent (Williams 1983).

The pollution components of urban runoff include suspended solids, phosphorous, nitrogen, heavy metals, bacteria, hydrocarbons and industrial chemicals. Some of the chemicals incorporated in these pollutants cause oxygen depletion of the receiving waters. All cause toxic effects to human and aquatic life.

The presence of suspended solids in the waters can have a number of adverse effects on aquatic ecosystems:

1. Light penetration may be reduced, resulting in decreased photosynthetic activity.
2. Nutrient availability may be affected because nutrients are absorbed onto the sediment.
3. There may be physical abrasion to, or clogging of, respiratory or feeding surfaces of various aquatic organisms.
4 Visibility may be reduced, affecting the ability of some organisms to capture prey.
5 The viability of those organisms that respond to changes in light intensity, as a behavioural stimulus for reproduction, may be affected.
6 The formation of deposits on streambeds and other surfaces, can inhibit spawning in some species of fish and can interfere with benthic (bottom dwelling) organisms and plants.

The concentrations of pollutants become more pronounced with declining stream flow. Studies have shown that the longer the length of dry spell the greater the level of pollutants in the stream during subsequent rainfall (Williams 1983). The lower baseflows experienced by some urban streams reduces the diluting benefit and when large quantities of cooling water are discharged into the stream an increase in water temperature can occur.

Wesche and Rechard (1973) in a study of the parameters influencing minimum streamflow, found that the parameter most severely reduced by flow reductions was velocity. They found that for an 85 % decrease in average daily flows, there was a 66.6 to 75.7% reduction in velocity. The greatest velocity decrease occurred for the interval between 25 % and 12.2 % average daily flow. More obviously, decreased flow rates cause a reduction in water depth, wetted perimeter and top width. These all have important implications for the survival of stream life.

2.4.2 CONSEQUENCES TO THE AVON RIVER

The consequences of the above mentioned factors for the Avon River during low flow periods are:

- deterioration of the highly valued scenic qualities of the river (e.g., exposure of river bed and rubbish, increased weed and algae growth);
- conditions unfavourable to aquatic life (decreased flow velocities, increased water temperature, siltation, increased weed and algae growth, habitat reduction);
- reduced dilution of contaminants; and
- reduced recreational and tourism opportunities by shallow water depth. (e.g., canoeing, commercial punting).

CHAPTER 3 INVESTIGATION OF THE AVON RIVER SYSTEM BASEFLOW

3.1 INTRODUCTION

In January and February of 1992, a reconnaissance of the Avon River system was carried out. The aim of the investigation was to locate suitable gauging sites on ten named tributaries and three flowing drains that occur upstream of the Gloucester Street bridge. At the same time, springs were located and headwater spring positions noted. Monitoring of the baseflow of the Avon River tributaries began on 16 February 1992 and continued until 22 January 1993. During this time, the streams were regularly gauged at the selected sites (Figure 3.1 and Appendix 3.1). At each site, a staff plate was installed and stage heights recorded. Since the study was concerned with the low flow characteristics of the Avon River, the monitoring of stage heights was conducted during non-flood periods. Following a large flood, stage heights were not recorded for several days. Because the Avon River storm hydrograph has a very steep recession curve (see section 2.3.1), this delay was found adequate for the surface runoff and interflow components of the streamflow to be removed from the catchment. The gauging site(s) for each tributary was positioned at the first suitable and readily accessible locality upstream of the tributary confluence. The result of the monitoring program is an eleven month record of tributary stage heights and monthly stream gaugings. Rating curves for each gauging site were drawn and the corresponding flow rates calculated from the recorded stage heights. The recorded data and rating curves for each tributary appear in Appendices 3.2 to 3.14.

Gauging sites were chosen for ease of access, sensitivity of control (ie a relatively large change in stage for a given change in flow) and stability. The stability of a site is a measure of how the stage discharge relationship (or rating) changes over time. A river level station at which ratings remain constant for long periods of time is said to have a stable control. Staff gauges were surveyed in position to allow replacement if removal by flooding or by disinterested parties occurred. No staff gauges required replacement.

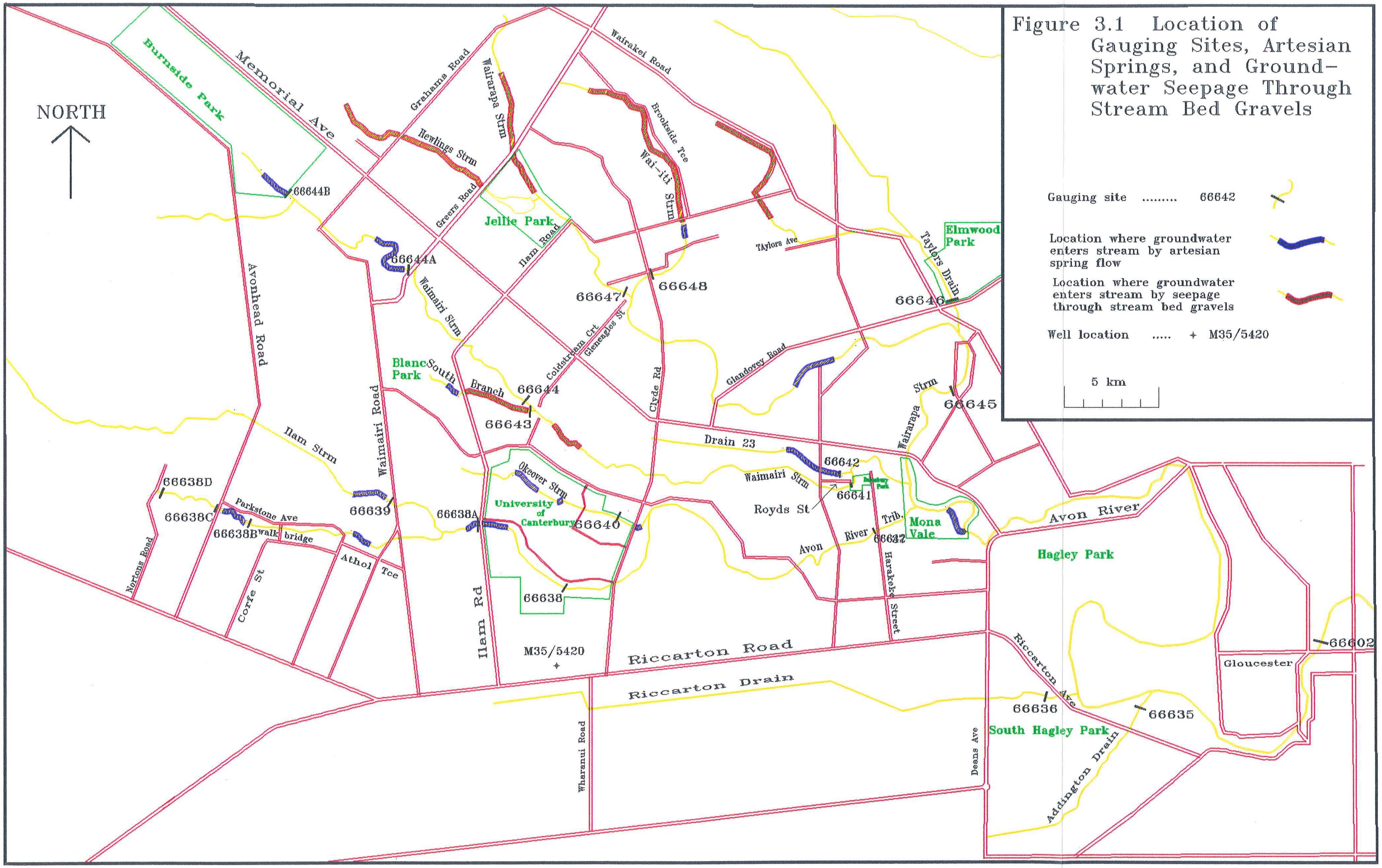


Figure 3.1 Location of Gauging Sites, Artesian Springs, and Groundwater Seepage Through Stream Bed Gravels

Gauging site 66642

Location where groundwater enters stream by artesian spring flow

Location where groundwater enters stream by seepage through stream bed gravels

Well location ..... + M35/5420

5 km

At some of the gauging sites, gaugings indicated that rating changes occurred due to a change in the channel profile during flood event or by weed removal. In the case of flood events, the Avon River record at Gloucester street was used to obtain the time period over which the rating change was thought to occur.

Secondary gauging localities for monitoring spring discharge on the Avon River Tributary and Waimairi Stream were established at suitable localities on the stream section (see Section 3.3).

Of the thirteen tributaries monitored, five had their streamflow augmented by artificial discharge from commercial activities (see Appendix 2.1). The artificial discharge was not constant and the flow record of streams that received it is more variable than those that did not. All streams showed increased discharge with increasing groundwater levels. The baseflow characteristics and streamflow record of each of the thirteen tributaries gauge sites are presented in the following section.

Analysis of the Avon River baseflow at Gloucester Street is presented in Section 3.4. Previous investigations on the Avon River flow regime (CDB 1980; Daglish 1985) are compared to the 1992-93 flow regime to establish whether a reduction in baseflow and contributing length has occurred. Small scale fluctuations in the Avon River flow hydrograph are investigated in Section 3.4.5.

Unless specified, all discussion on stream flow refers to baseflow.

3.2 BASEFLOW CHARACTERISTICS OF THE AVON RIVER TRIBUTARIES

The five tributaries that discharge directly into the Avon River upstream of Gloucester Street are referred to in this study as first order tributaries. These are: Addington Drain, Riccarton Drain, Avon River Tributary, Waimairi Stream and Wairarapa Stream. Drain 23 is included in the first order tributaries because it discharged into the Waimairi downstream of the Waimairi gauging site. Figure 3.2 shows the flow records for the first order tributaries. Table 3.1 contains mean monthly flow rates, and percentage of Avon River flow at Gloucester Street contributed by the first order tributaries. The remaining tributaries which discharge into the first order tributaries are referred to as second order tributaries. Figure 3.3 shows the second order tributaries' flow record. Table 3.2 contains the mean monthly flow rates, and percentage of Avon River flow at Gloucester Street contributed by the second order tributaries.

Table 3.1 shows that the difference between the mean tributary baseflow (1453 l/s) and mean Avon River baseflow recorded at Gloucester Street (1721 l/s) is 286 l/s. A flow of 286 l/s corresponds to 16% of the mean baseflow at Gloucester Street. This data indicate that 16% of the Avon River baseflow at Gloucester Street enters the river downstream of approximately Mona Vale.

3.2.1 ADDINGTON DRAIN

Addington Drain is a man-made drain which enters the Avon River on true river right in Hagley Park. A gauging site (66635) was established in Hagley Park, 100 m upstream of the drain confluence with the Avon River. Addington Drain exits a stormwater pipe at Deans Avenue, and there is minimal open drain upstream of this point. Addington Drain flowed during the entire study period, but no natural springs were observed in the stream channel. However, several tile drains on true river right in South Hagley Park provided continual discharge into the stream. It is likely that these either drain historical spring locations which were subsequently buried during the development of the Addington area, or areas of high watertable. The fluctuation in the Addington Drain streamflow record is due to artificial discharge into the drain from Alpine Dairy Products (up to 646 m^3/day). Although the maximum baseflow coincided with high groundwater levels, Addington Drain showed a very small response to groundwater level fluctuations.

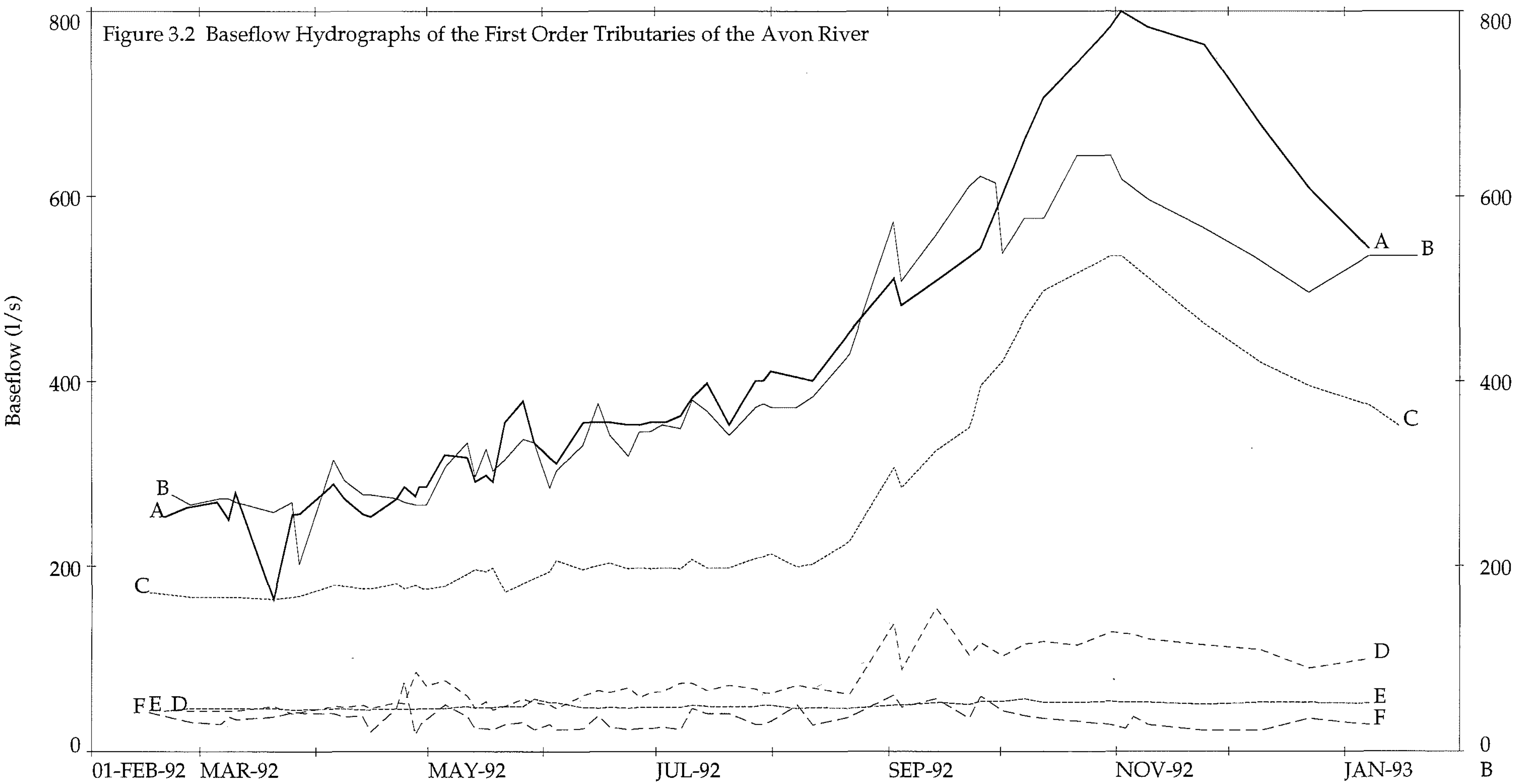


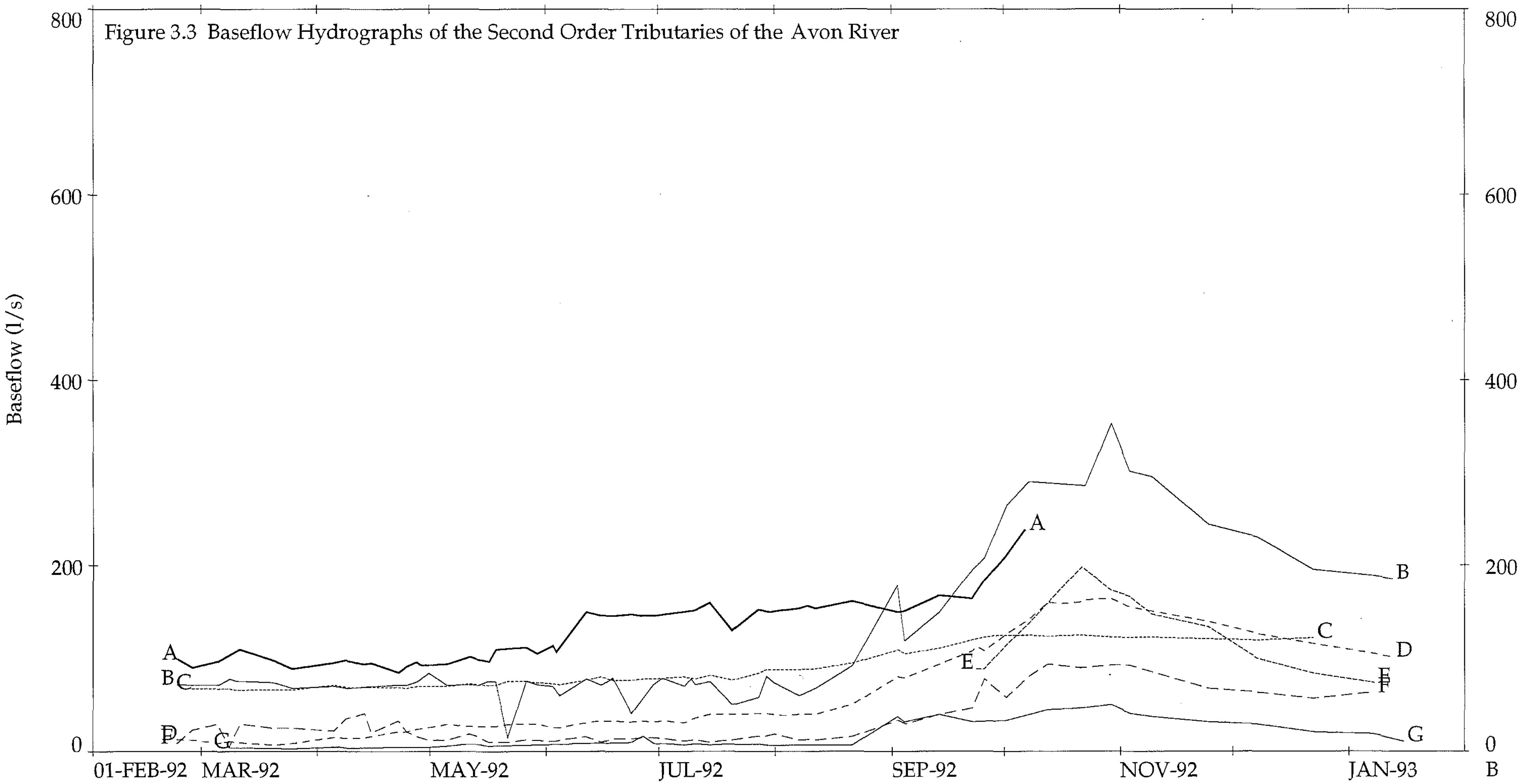
Figure 3.2 Baseflow Hydrographs of the First Order Tributaries of the Avon River

A —— site 66637 Avon River Tributary at Harakeke Street bridge flow l/s
B —— site 66645 Wiarapapa Stream at Garden Road bridge flow l/s
C ········ site 66641 Waimairi Stream at Daresbury Park flow ls
D - - - - site 66636 Riccarton Main Drain at Riccarton Avenue flow l/s
E -------- site 66642 Drain 23 at 7 Royds Street flow l/s
F — — — site 66635 Addington Drain at Hagley Park flow l/s

Table 3.1 Mean Monthly Baseflows (l/s) of First Order Avon River Tributaries (1992-93)									
	Tributary Name and gauging site								
	Addington Drain [66635]	Riccarton Drain [66636]	Avon River Tributary [66637]	Waimairi Stream [66641]	Drain 23 [66642]	Wairarapa Stream [66645]	**Trib. Total**	**Avon River @ Gloucester Street**	**Flow Unaccounted For**
February	37	44	259	169	43	272	824	1266	442
March	37	45	242	167	47	260	798	1239	441
April	39	54	273	178	46		590	1300	710
May	33	58	325	186	49	316	967	1440	473
June	27	60	346	200	49	332	1014	1485	471
July	35	69	378	203	49	361	1095	1575	480
August	41	77	437	227	48	424	1254	1682	428
September	51	121	521	339	52	573	1657	2213	556
October	35	117	712	496	54	605	2019	2534	515
November	27	119	782	491	52	585	2056	2452	396
December	29	100	643	409	53	519	1753	2162	409
January	29	100	552	364	54	537	*	1952	*
Ratio of the range in mean monthly baseflow to mean tributary baseflow (%)	47	64	69	66	22	55	N/A	51	N/A
Mean tributary baseflow	35	81	456	409	50	398.6667	1430	1721	292
% Mean Avon River baseflow	2	5	26	24	3	23	83	100	17

* not included because tributary baseflow data is only up until mid-January 1993

Figure 3.3 Baseflow Hydrographs of the Second Order Tributaries of the Avon River



A ——— site 66638 Avon River Trib at University [Rec Cent] flow l/s
B ——— site 66647 Wairarapa Stream at 42 Gleneagles Tce flow l/s
C ········ site 66646 Taylors Drain at Elmwood Park flow l/s
D - - - - site 66643 South Branch Waimairi at Barlow street flow l/s
E -·-·-·- site 66644 Waimairi Stream at Coldstream Court flow ls
F — — — site 66640 Okeover Stream at University (Forestry) flow l/s
G ——— site 66648 Wai-iti Stream at Clyde Road flow l/s

Table 3.2 Mean Monthly Baseflows of Second Order Avon River Tributaries (1992-93)										
	Avon River Tributary @ University [66638]	Okeover Stream @ University [66640]	Ilam Stream@ Waimairi Road [66639]	South Branch @ Barlow Street [66643]	Waimairi Stream @ Coldstream Crt [66644]	Taylors Drain @ Elmwood Park [66646]	Wairarapa Stream @ Glenaegles St [66647]	Wai-iti Stream @ Clyde Road [66648]	Hewlings Stream@ Jellicoe Park	**Avon River @ Gloucester St**
February	94	16	0	12	0	67	71		*35*	1266
March	98	24	0	9	1	67	73	4	*35*	1239
April	93	26	0	18	1	69	71	4	*35*	1300
May	103	13	0	28	1	73	66	7	*35*	1440
June	139	13	0	31	4	76	66	10	*35*	1485
July	148	14	0	38	9	81	67	8	*35*	1575
August	156	17	0	50	26	94	92	12	*35*	1682
September	169	46	2**	98	76	114	174	35	*35*	2213
October	309	86	35	154	164	124	297	48	82	2534
November	?	79	32	146	143	122	274	30	75	2452
December	?	61	?	121	92	121	212	37	*35*	2162
January	?	67	?	103	71	?	190	26	*35*	1925
Ratio of the range in mean monthly baseflow to mean tributary baseflow (%)	?	84	100	94	100	45	78	91	N/A	N/A
Mean tributary baseflow	145	38	?	69	40	93	139	26	41	1721
% of Mean Avon River baseflow	8	2	?	4	2	5	8	2	2	N/A

* Data in italics is the average of Hewlings Stream gaugings when Aqualand discharge was sole source of stream flow

** Estimated

3.2.2 RICCARTON MAIN DRAIN

Riccarton Main Drain is a man-made drain which enters the Avon River on the true river right in Hagley Park. A gauging site (66636) was situated 10 m upstream of the Riccarton Avenue bridge. At the gauging site, the drain is a concrete box section and all non-flood flows are contained within the concrete boxing. Streamflow is augmented by artificial discharge, of up to 8 l/s, from MAF Fisheries on Kyle Street. The drain continues upstream as an open waterway to Wharanui Road where water exits a stormwater drain. Downstream, streamflow increases by input from numerous stormwater pipes, which during periods of high groundwater levels supplied a continuous contribution to streamflow. Presumably, these pipes tap springs that were buried during the development of the Riccarton area or areas of high watertable. Historical springs are known to have existed on properties adjacent to Deans Avenue (pers. com., Mr Thwaits, resident at 55 Brookside Terrace).

3.2.3 AVON RIVER TRIBUTARY

The modern day headwater source of the Avon River is a stormwater drain pipe at 70 Nortons Road, 5 m upstream from gauging site 66638D. Throughout the study period, the stormwater drain discharged a constant 5 l/s into the Avon River Tributary. The pipe probably drains buried springs or an area of high watertable to the west of Nortons Road.

The gauging site on the Avon River Tributary at Harakeke Street (66637) was 250 m upstream of the confluence of the Avon River Tributary with Wairarapa Stream. Streamflow at this point is the total discharge received from Avon River Tributary, Okeover Stream and Ilam Stream. No spring contribution to the Avon River was observed by the author downstream of the University, but the streamflow data show that a relatively large increase in flow occurs downstream of the University. This increase is due to groundwater input that is not sufficiently vigorous to be observed. Spring vents were observed by the ground staff at Mona Vale during the drainage of the Mona Vale pond for weed removal (pers comm., Mona Vale ground staff).

Observed spring contributions to the Avon River Tributary occur in three sections of the stream between the University of Canterbury Student Union Association building and Avonhead Road bridge (Figure 3.1). At the time of maximum spring contribution to the stream, in excess of 100 vents were observed along this section. The vents occurred in swarms, which made determination of individual discrete spring contributions impractical. As a compromise, gauging sites were established upstream and downstream of the spring sections at Avonhead Road (66638C), upstream of Parkstone Road-Corfe Street footbridge (66638B), and at Ilam Road (66638A) (Figure 3.1). Gauging site 66638D measured discharge from the stormwater drain at 70 Nortons Road.

Artificial discharge enters the Avon River Tributary as it flows through the University Campus. The water is used as cooling water for air-conditioning plants and discharges of up to 30 l/s were measured during the summer months. 0 to 5 l/s were measured during the winter.

3.2.3.1 Okeover Stream (Clarkson Drain)

Okeover Stream discharges into the Avon River Tributary 150 m downstream from Clyde Road. The flowing section of the stream channel begins at a stormwater pipe at the University Halls, Ilam. A continual, but less than 1 l/s flow was observed discharging from the pipe throughout the study period. This flow is likely to originate from either buried springs (a high concentration of springs occur in the vicinity) or leakage from underground pipes beneath University Halls. The gauging site (66640) was located in the University campus adjacent to the PAMS Department glass house.

Okeover Stream flows through the University campus where it receives the majority of its summer streamflow from artificial discharge (up to 84 l/s) of air conditioning cooling water. An additional 83 m^3/day is periodically discharged into the stream from the Engineering Department Fluid Mechanics Laboratory.

A large number of small artesian springs occur in the stream channel (Figure 3.1), but spring input during the period of low groundwater levels from February 1992 to July 1992 was very minimal (1 to 2 l/s). The spring identified by Daglish (1985), 3 m downstream of Clyde Road, did not begin flowing until July 1992 when groundwater levels in the area began to rise.

3.2.3.2 Ilam Stream

Ilam Stream discharges into the Avon River Tributary in the grounds of Ilam Homestead, approximately 200 m upstream of Ilam Road. The stream is dammed by a man-made weir at its confluence with the Avon River Tributary. The weir creates a pond with its upstream limit 20 m below Waimairi Road bridge. No non-flood flow occurred across the weir from the period February 1992 to August 1992, but high groundwater levels caused springs to flow in a 200 m stream section from Waimairi Road to the Teachers College (Figure 3.1). Streamflow across the weir continued until early February 1993. Streamflow in Ilam Stream was gauged on two occasions at the Waimairi Road (see Table 3.2).

3.2.4 WAIMAIRI STREAM

The Waimairi Stream discharges into the Wairarapa Stream at Mona Vale and has two main tributaries, the South Branch and Drain 23. The Waimairi Stream gauging site (66641)was located at the western end of Royds Street, 300 m upstream of the Wairarapa Stream confluence and upstream of Drain 23's discharge location. The stream receives no artificial discharge and all dry weather streamflow is groundwater derived. The western limit of the open stream channel is a stormwater pipe in Burnside Park. Swarms of artesian springs occur at two localities along the course of the stream (Figure 3.1). No observed spring discharge occurred upstream of the South Branch confluence from February 1992 to July 1992. A second gauging site on Waimairi Stream was located at Coldstream Court (66644).

In mid-July 1992, a relatively large swarm of springs at 59 and 61 Greers Rd began to flow. In mid-September, approximately two weeks after the heavy August rainfall events, springs in Burnside Park began to flow. These springs had stopped flowing in the summer of 1984-85 and in the following years had only flowed for brief periods following very heavy winter rainfalls (pers. comm., Mrs Chappel, resident). At the time of peak groundwater levels in October/November 1992 the headwater spring of the Waimairi Stream was 50 m downstream of Avonhead Road.

The springs immediately upstream of Greers Road (at 59 and 61 Greers Road) have also shown a very noticeable decline in discharge over the last 10 years, and during the summers of 1989-90 ceased to flow for the first time in the thirty years that Mrs Moros owed the property. The springs also went dry during the summers of 1990-91 and 1991-92. Mrs Moros noted that the drying of the springs coincided with the new housing development in Avonhead. Similarly, 100 m upstream, springs were observed to stop flowing for the first time over the summer of 1984-85 and have been dry more often than not ever since.

3.2.4.1 Drain 23

Drain 23 discharges into the Waimairi Stream 50 m downstream of gauging site 66641. The drain receives no artificial discharge and flow occurred along the entire length of the open stream channel which begins immediately west of Clyde Road. Springs found in the stream upstream of Royds Street (Figure 3.1), flowed throughout the study period. The gauging site on Drain 23 (66642) was located at 7 Royds Street, 3 m downstream of a relatively large isolated spring. The stream was gauged several times upstream of the spring to ascertain the seasonal fluctuation in spring flow. The results of these measurements appear in Section 5.3.2.1.

3.2.4.2 South Branch (Waimairi) Stream

The South Branch Stream discharges into the Waimairi Stream 20 m downstream of the South Branch Stream gauging site (66643). The stream receives no artificial input and streamflow occurred throughout the study period. From February to mid-August 1992, the upstream limit of the contributing channel length was seepage through gravels immediately downstream of the Ilam Road. The South Branch is an open stream channel to Blanc Park, where it enters a stormwater drain and then reappears for a short distance west of Waimairi Road as an open drain.

Two relatively large springs, 100 and 125 m upstream from Clyde Road (at 177 Ilam Road) were dry up until mid August 1992 (two weeks prior to late-August rainfall events). In early September, springs also appeared 150 to 200 m upstream from Ilam Road (at 181 Ilam Road). The springs at 177 Ilam Road continued to flow until monitoring stopped in February 1993, although at steadily decreasing rates.

During the period of high groundwater levels small headwater springs were located in the streambed muds, immediately upstream of Waimairi Road.

3.2.5 WAIRARAPA STREAM

The Wairarapa Stream discharges into the Avon River at Mona Vale. Three tributaries which contribute to the base-flow of the Wairarapa, are moving progressively upstream: Taylors Drain, Wai-iti Stream and Hewlings Stream. Two gauge sites were established on the Wairarapa; the furthest downstream at the Garden Road (66645) measures the total stream contribution of the tributaries, and the other 20 m upstream of the Wai-iti Stream confluence at 42 Gleneagles Street (66647), measures the contribution from the upper Wairarapa and Hewlings Streams.

The majority of Wairarapa streamflow at site 66647 is derived from discharge into Hewlings Stream at Jellie Park from the Aqualand Swimming Pool's heat exchange system. From February 1992 to August 1992, natural streamflow in Wairarapa Stream was initiated from seepage through gravels in Jellie Park. In September the headwaters of Wairarapa Stream migrated upstream to begin flowing from seepage through the gravel between Grahams and Greers Roads.

3.2.5.1 Taylors Drain

Taylors Drain flows into the Wairarapa Stream 100 m south of the Wairakei Road and Glandovey Road intersection. The gauging site (66646)was located 150 m upstream of this confluence at the southwestern corner of Elmwood Park. The drain receives no known artificial discharge and summer stream flow was initiated from seepage through gravel between Ilam Road and Wairakei Road in the summer. During the winter, gravel seepage migrated upstream, and streamflow began 500 m upstream of the Ilam Road Wairaiki Road intersection.

3.2.5.2 Wai-iti Stream

Wai-iti Stream discharges into the Wairarapa Stream 100 m downstream of Clyde Road. A gauging site was installed immediately upstream of Clyde Road (66648). There are no discharge consents for input into the stream, and the small unexplained fluctuations in the stream flow record are probably due to input from domestic activities. The headwater source throughout much of the study period was from seepage through gravels beneath the Ilam Road bridge. In October 1992, the headwaters migrated upstream to approximately 200 m downstream of Greers Road. Three historical springs are known to have been located at 75 Brookside Terrace, where an area of silty sand occurs in the channel of Springston Formation gravels (pers. comm., Mr Thwaits, resident). Mr Thwaits recollected that twenty years ago (1972) the Wai-iti Stream at 75 Brookside Terrace flowed year round with approximately 30 cm of water in the channel. Since then the baseflow has steadily declined, and today (1 October 1992) the water in the stream channel at 75 Brookside Terrace was only 2 cm deep. This was approximately the time of maximum seasonal groundwater levels in the area. For ten of the eleven months the data was collected for this study, this stream section was completely dry.

3.2.5.3 Hewlings Stream

Hewlings Stream receives discharge from Aqualand at Jellie Park. From February to September 1992, this was the sole source of stream flow, but from September to

November the stream section upstream of Greers Road began flowing. The headwater source was from seepage through gravels that migrated slowly upstream until mid-October, when the entire length of the stream section was flowing. This was the first time in approximately 20 years that there had been dry weather flow in the upstream section of the channel (pers. comm., Lorna Hinds, resident). The streamflow was gauged on several occasions at Greers Road and at the weir in Jellie Park (Table 3.2).

3.3 SPRING FLOW REGIME

Prior to this project, spring discharge into the Avon River was known to occur near the thinner western margin of the surface confining layer (NCCB 1986). This was substantiated in the course of the study; groundwater was contributed to the Avon River from artesian springs and seepage through stream bed gravels in western suburbs of Christchurch. Springs tend to occur in swarms, with up to several dozen discrete springs flowing in a 100 m section of stream. Where the headwaters of a stream begin by seepage through stream bed gravels, streamflow would steadily increase downstream without observable flowing artesian springs (e.g., Wairarapa Stream, Wai-iti Stream, Taylors Drain, lower section of South Branch Stream). Where the stream originated in an artesian spring section, flow would begin by indiscernible seepage through fine sediment in the stream bed immediately upstream of the springs. Downstream, flowing artesian springs become progressively larger and more numerous (e.g., Waimairi Stream, upper section of South Branch Stream, Avon River Tributary, Okeover Stream, Ilam Stream).

In all tributaries, flow rates increased downstream. However, artesian spring discharge into the more eastern (downstream) sections of the tributaries was not observed even though the downstream recorded flow rates showed an increase in stream flow. This may be because the more vigorous stream flow in the downstream sections obscured artesian spring discharge or the eastward thickening of the surface confining layer inhibited artesian spring occurrence. In the case of the latter, lateral flow of groundwater into the stream may dominate. Shallow watertable levels become progressively closer to the surface eastward (Figure 2.4) which suggests that a change in the process by which groundwater enters the stream may occur in the eastern section of the study area.

3.3.1 AVON RIVER TRIBUTARY FLOW REGIME

Figure 3.4 is a plot of the Avon River Tributary flow regime. Data for the figure appears in Table 3.3 and location of the gauging sites is shown in Figure 3.1. The discharge from the Okeover Stream has been removed from the flow record at Harakeke Street, but artificial discharge that enters the Avon River at the University has been left in. At least half of the increase in the summer stream flow between Ilam Road and the University is a result of University discharge. However, in the winter months discharge from the University was less than 1 l/s and the increase between Ilam Road and the University is a result of natural groundwater input.

The increase in stream flow between Avonhead Road and Corfe Street is from a large group of artesian springs that occur upstream of the Corfe Street-Parkstone Ave walk bridge (Figure 3.1). The flow increase between the walk bridge and Ilam Road is largely due to two sections of the river where flowing artesian springs occur (the sections immediately downstream of Parkstone Avenue, and 50 m downstream to 100m upstream of Ilam Road). Downstream of the latter no flowing springs were observed but as mentioned above, stream flow more than doubled between the University and Harakeke Street.

3.3.2 WAIMAIRI STREAM SPRING FLOW REGIME

Figure 3.5 is a plot of the Waimairi Stream flow regime. Data for the figure is in Table 3.4 and location of the gauging sites is sown in figure 3.1. The contribution of the South Branch Stream to the Waimairi Stream has been removed from the Waimairi flow record at site 66641 (Daresbury Park).

Figure 3.4 Avon River Tributary Flow Regime

* Position on axis indicates approximate position from headwater location (70 Nortons Rd)

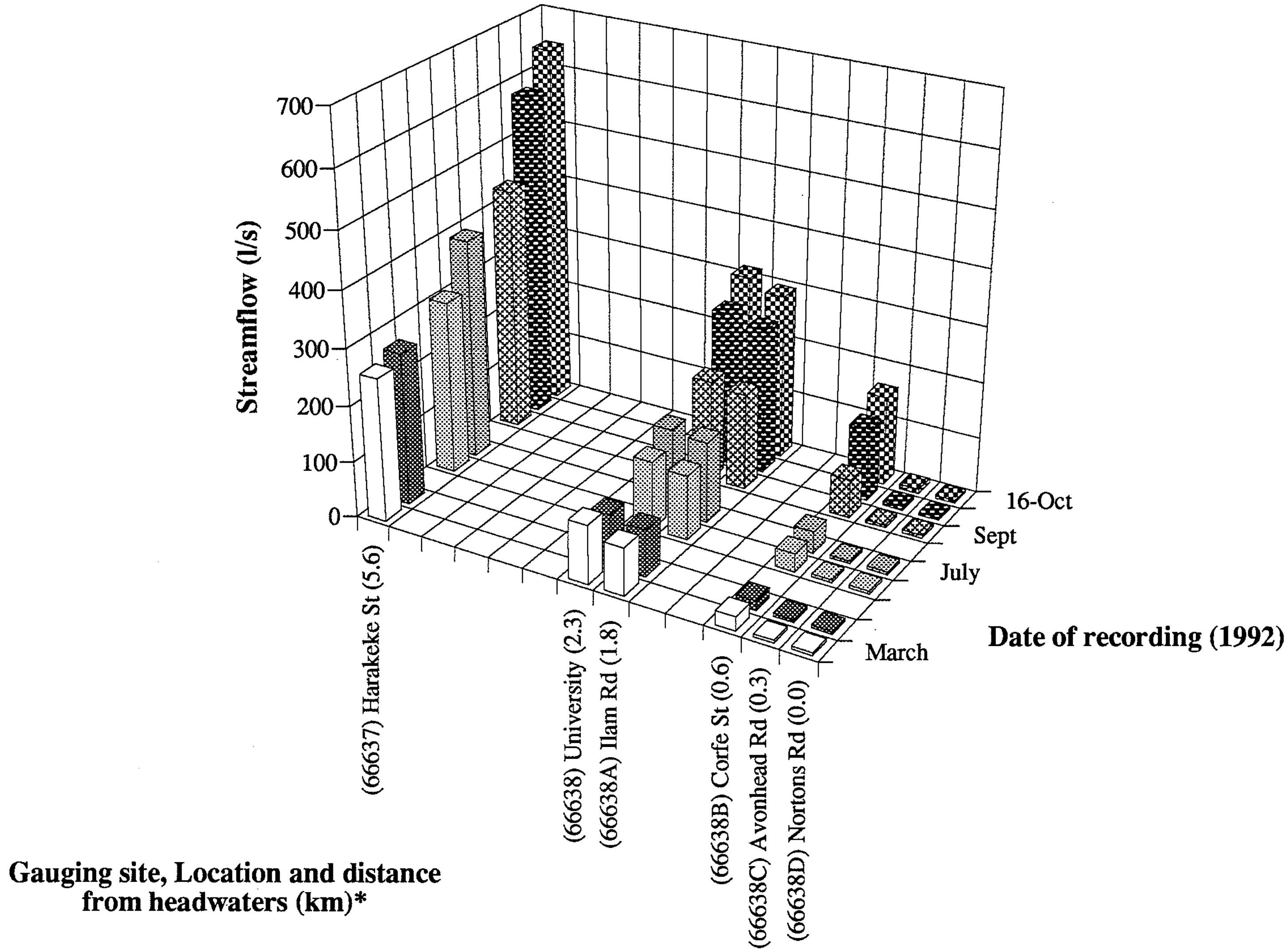


Table 3.3 Avon River Tributary 1992 Flow Regime (flow in l/s)

Stream	**Location and gauging site**	**Distance downstream from head waters (km)**	**Date (1992)**							
			March	April	June	July	Sept	6-Oct	16-Oct	Average % increase for study period
Avon River Trib.	Nortons Rd (66638D)	0.00	5	5	5	5	5	5	5	
Avon River Trib.	Avonhead Rd (66638C)	0.30	5	5	5	5	5	7	8	
Avon River Trib.	Corfe St (66638B)	0.60	25	17	32	39	69	132	160	
Ilam Stream	Waimariri Rd (66639)	N/A	0	0	0	0	?	32	35	
Avon River Trib.	Ilam Rd (66638A)	1.80	85	83	115	144	171	261	295	
Avon River Trib.	University (66638)	2.30	105	90	122	150	179	*275*	*315*	
Okeover Stream	University (66640)	N/A	25	15	11	18	33	80	92	
Avon River Trib.	Harakeke St (66637)	5.60	280	286	318	410	467	660	735	
Avon River Trib. with Okeover Stream flow deducted	Harakeke St		255	271	307	392	434	580	643	
% increase in flow between University and Harakeke Street			41	33	40	38	41	47	49	41
% increase in flow between walkbridge and Ilam Rd			34	31	38	37	40	46	46	39

* Data in italics is not accurate as weed growth is thought to have caused a gauging error. Upstream flow data recorded at Ilam Rd suggests the error is not greater than approximately 10 l/s.

Figure 3.5 Waimairi Stream Flow Regime (mean monthly flow)

*Position on axis indicates approximate distance from winter headwater position

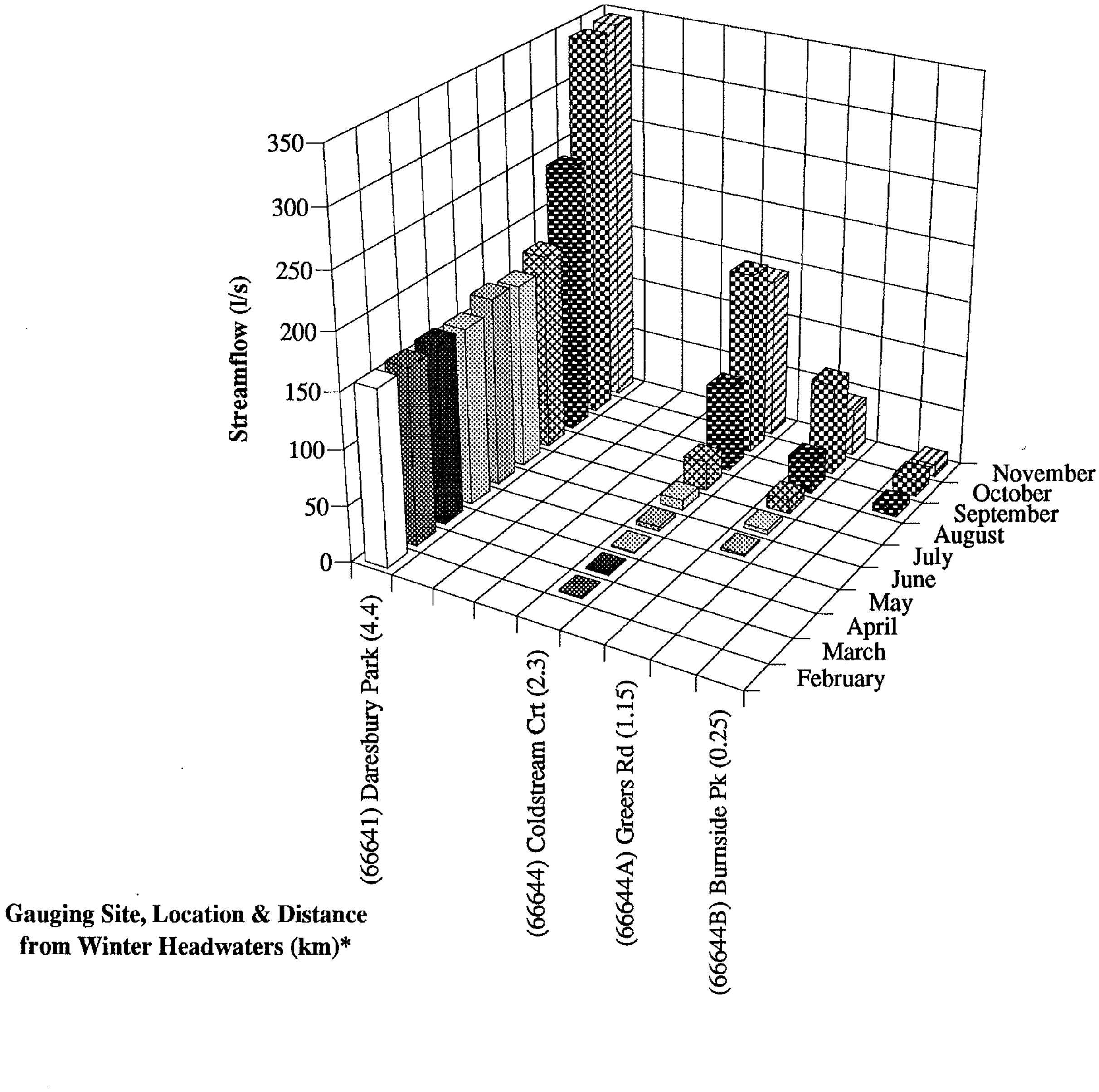


Table 3.4 Waimairi Stream 1992 Flow Regime (flow in l/s)												
Stream	**Location and gauging site**	**Distance downstream from head waters (km)**	**Date**									
			Febuary	March	April	May	June	July	August	September	October	November
Waimairi	Burnside Park (66644B)	0.25	0	0	0	0	0	0	0	7	15	11
Waimairi	Greers Rd (66644A)	1.15	0	0	0	0	2	4	12	30	83	43
Waimairi	Coldstream Crt (66644)	2.30	0	1	1	1	4	9	26	76	164	143
South Branch	Barlow Street (66643)	N/A	12	9	18	28	31	38	50	98	154	146
Waimairi	Daresbury Park (66641)	4.40	169	167	178	186	200	203	227	339	496	491
Waimairi with South Branch flow deducted	Daresbury Park	4.40	157	158	160	158	169	165	177	241	342	345
% of Waimairi stream flow that enters the stream between Coldstream Crt and Daresbury Park			100	99	99	99	98	95	85	68	52	59
% of Waimairi sytream flow that enters the stream between Burnside Park and Coldstream Crt			0	1	1	1	2	5	15	32	48	41
Contribution to stream flow between Coldstream Crt and Daresbury Park			157	157	159	157	165	156	151	165	178	202

From February to July 1992, flow at Coldstream Court was between 0 and 4 l/s. At the end of July, artesian spring flow started in a 100 m stream section immediately upstream from Greers Road (Figure 3.1). In September, a second group of springs at Burnside Park began to flow. Downstream of Coldstream Court, no springs were observed, but seepage from gravels in the stream bank was observed between Coldstream Court and Clyde Road (Figure 3.1).

The percentage increase of Avon River Tributary stream flow (relative to Harakeke Street flow) between University and Harakeke Street, and Avonhead Road and Ilam Road, is shown in Table 3.3. The data show that on average the Avon River Tributary receives 39% of its base flow from the 1.2 km stream section between Avonhead and Ilam Roads and 41% from the 3.3 km section between University and Harakeke Street.

Synthesis of Section 3.3

In the case of the Waimairi Stream, during October, the time of maximum stream flow, 41 % of the flow originated from the 2.3 km section upstream of Coldstream Court and 58% from the 2.1 km section between Coldstream Court and Daresbury Park (Table 3.4). However, for six of the ten months that records were kept, the percentage of stream flow from the section upstream of Coldstream Court was less than 5%. These figures indicate that during periods of high groundwater level a significant portion of flow originates from the western headwater sections of the streams. Both streams have isolated sections where relatively large increases in stream flow occurs from groundwater input.

The geological character of the near surface sediments appears to dictate the spatial distribution of groundwater discharge to the stream (see Chapter 4). The identification of stream sections where relatively high rates of ground water discharge into the stream could have an application in the management of groundwater abstraction to help maintain the baseflow of spring fed streams.

3.4 AVON RIVER BASEFLOW ANALYSIS

3.4.1 INTRODUCTION

The Avon River stream flow is recorded immediately downstream of the Gloucester Street bridge (site 66602) at grid reference S84:003563, 14.9 km from the mouth. At this site, gaugings are carried out by wading during low flow periods and from the bridge during flood events. The period of recorded data is from 14 August 1980 and present, with a large gap of missing data between 21 August 1986 to 30 April 1991. The recording authorities from 1980 to 1986 were the Christchurch Hydrological Survey and the Christchurch Drainage Board. In April 1991, the Canterbury Regional Council installed a Fisher and Porter recorder.

Most of the flow record is of poor quality due to periods when insufficient gaugings were conducted to derive the stage height - flow relationship. In some years, weed growth (mainly in spring and autumn) caused the record to show either, a gradual rise in water level or a constant water level, when stream gaugings showed a reduction in flow . The record was checked, by the hydrologist at the Canterbury Regional Council against shallow water levels, with the assumption that if the groundwater levels increased then groundwater flows into the Avon River also increased. However, if groundwater levels did not increase then the rise in river level was due to weed growth. Those periods of the record where discrepancies between river levels and groundwater levels occur, and when an inadequate frequency of gaugings were conducted to allow accurate ratings to be derived, have not been used in this study.

To ascertain whether there has been any noticeable trend in Avon River low flow regime, the data from two previous investigations (CDB 1980 and Daglish 1985) are compared to the 1992-93 low flow periods (Section 3.4.4).

3.4.2 BASEFLOW SEPARATION METHOD

The term base-flow is defined as the portion of flow that comes from groundwater storage or other delayed sources (Hall 1969). Although numerous techniques, which vary in both complexity and precision, have been developed for the separation of base-flow from surface runoff, they all achieve only an approximation of base-flow. Most of the procedures are based on physical reasoning, but the qualitative elements of the separation techniques are essentially arbitrary and the precise 'unknown' form of the base-flow hydrograph is dependent upon the hydrological and geomorphological conditions in the catchment. Different authors have applied different rules regarding the cessation of surface runoff and the time of peak base-flow discharge. To help minimise subjectivity, several investigators have attempted to estimate actual base-flow conditions by tracer experiments and chemical analyses. (e.g., Pinder and Jones 1969; Pilgrim et al 1979; Sklash and Farvolden 1979). When baseflow separation needs to be performed on a large amount of data, the method of separation needs to be easy to apply and able to be applied to the data with consistency.

In this study, the base-flow of the Avon River was separated by fitting a straight line from the start of the hydrograph rise to the baseflow separation point on the recession limb determined by the intersection of two straight recession lines on plots of logarithmic flow versus time (Figure 3.6) (Pilgrim 1987, Horrell 1992). This method of baseflow separation is used by hydrologists at the Canterbury Regional Council and was applied using the editing facilities in TIDEDA.

3.4.3 TREND IN AVON RIVER BASEFLOW

As mentioned, much of the historical Avon River flow data is of poor quality and cannot be used in low flow analysis. Time series flow data have only been recorded since August 1980, so a quantitative assessment of a long term trend in flow can not be made.

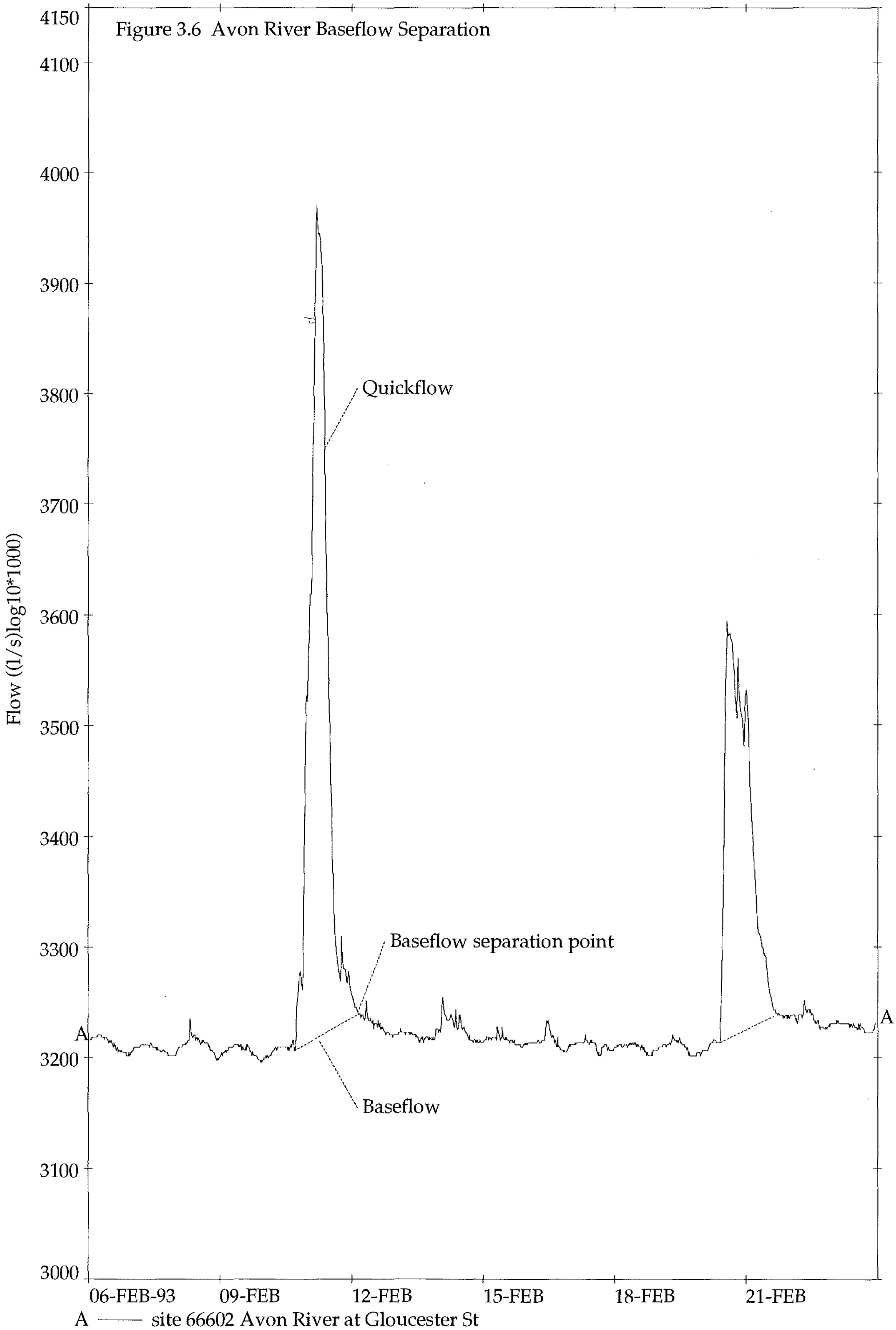


Figure 3.6 Avon River Baseflow Separation
Flow ((l/s)log10*1000)
4150
4100
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
3000
Quickflow
Baseflow separation point
Baseflow
A
A
06-FEB-93
09-FEB
12-FEB
15-FEB
18-FEB
21-FEB
A —— site 66602 Avon River at Gloucester St

The lowest mean monthly baseflow for the reliable data of the Avon River at Gloucester Street, occurs from December to May (Figure 3.7 and Table 3.5). A linear regression line through the mean monthly baseflows during the months December to May from 1981 to 1992 shows a decline in flow with time (slope = -1.93 per month)(Figure 3.7). A second regression line in Figure 3.7 incorporates the data from the period December 1992 to February 1993; the more recent data reflect the recovery from low baseflow conditions in recent years with essentially no trend indicated (R^2 = 0.03). The mean baseflow in February 1993 was only 3% less than the mean baseflow in March 1981. It should be noted that February is not usually the month in which the lowest mean monthly baseflow occurs. The return to higher baseflow rates during the summer 1992-93 can be attributed to the very wet spring of 1992 which caused a large rise in groundwater levels (see Chapter 5). The only conclusion that can be drawn from this is, that while Avon River baseflow may be declining over the long term (i.e., longer than the 13 years of record), periods of high rainfall totals can return the baseflow to a level similar to 1980, when measurements began.

3.4.4 COMPARISON OF THE AVON RIVER LOW FLOW REGIME IN THE YEARS 1980, 1985, 1992 & 1993

In 1980, the Christchurch Drainage Board carried out a biological survey of Christchurch urban streams (CDB 1980). The survey was not intended as a low flow analysis and although the study incorporated a relatively large number of stream flow measurements on the Avon River system, the records for those gaugings were not kept. The errors incorporated in the measurements are not known and could be high. The report was published in March 1980, but it is not known when the measurements where carried out. Verification of whether these data are representative of baseflow is not possible. It is presumed that the measurements were taken some time during the summer of 1979/80.

Daglish (1985) investigated the low flow regime of the Avon River by gauging streamflow at the some of the same localities as the CDB (1980) survey. After comparing the flows, Daglish concluded that the total streamflow contribution of the

Figure 3.7 Mean Monthly Baseflow of the Avon River at Gloucester Street with Trend Lines

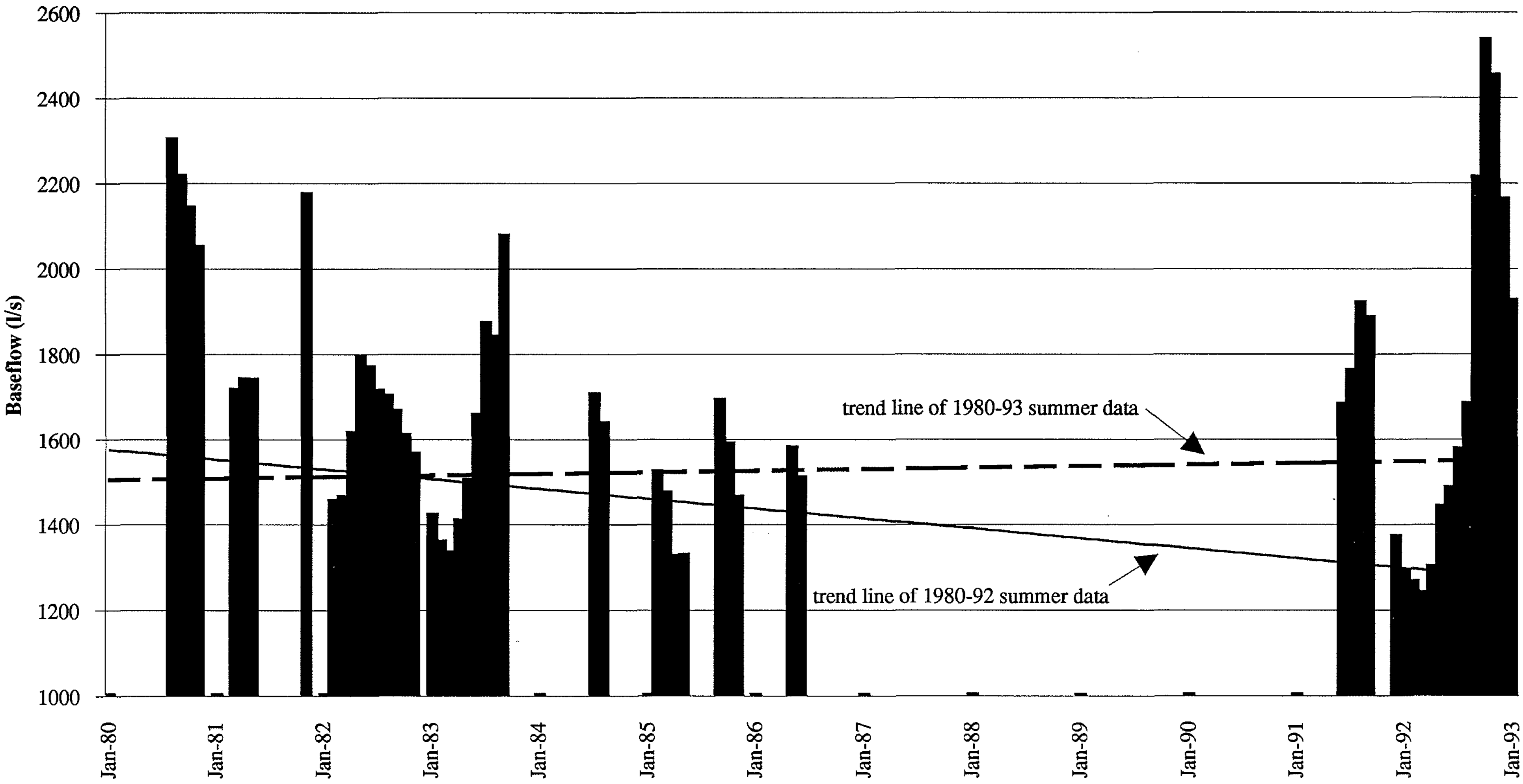


Table 3.5 Avon River at Gloucester Street Mean Monthly Baseflows 1980 to 1993													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Mean**
1980								2301	2216	2141	2055		
1981			1715	1740	1739	1768					2173		
1982		1454	1463	1613	1792	1656	1713	1701	1665	1609	1565		
1983	1420	1358	1333	1407	1503		1872	1840	2076				
1984		1522					1705	1637					
1985			1473	1325	1327					1588	1463		
1986					1579	1509							
1987													
1988													
1989													
1990													
1991						1681	1760	1919	1884			1371	
1992	1291	1266	1239	1300	1440	1485	1575	1682	2213	2534	2452	2162	1721
1993	1925	1656											
Min	1291	1266	1239	1300	1327	1485	1575	1682	1665	1588	1463	1371	1438
Mean	1545	1451	1445	1477	1563	1620	1725	1847	2011	1968	1942	1767	1697
Max	1925	1656	1715	1740	1792	1768	1872	1919	2213	2534	2452	2162	1979

* Gaps represent missing or unreliable data

three main tributaries (Avon River Tributary, Waimairi Stream and Wairarapa Stream) in April 1985 was 58% of that in the summer of 1979/80. The flow data from CDB (1980), Daglish (1985) and that obtained during this study appear in Table 3.6. The locations and results of the gaugings are shown in Figure 3.8.

Several deficiencies occur in the comparison of the flow rates between the three studies:

1. The flow was not recorded at the same locations in each study. The different locations are shown in Figure 3.8 and while the distance between representative locations is not great, some error in the comparison will occur.
2. The data from CDB (1980) and Daglish (1985) are once-off readings while the data from this study are from mean monthly flow levels.
3. It is not known if the CDB data were obtained during low flow conditions.

3.4.4.1 Decline in Tributary Contribution

The data (Table 3.6) indicate that Avon River system summer low flow rates continued to decline between 1985 and 1992. The baseflow in 1992 was 64% of that in 1985. Large rainfall events in the spring of 1992 caused relatively high groundwater levels to occur throughout the summer of 1992/93. As a result, the flow in January 1993 was 42% higher than in April 1985 and only 18% lower than in March 1980. It should be noted that the 1993 data is from the month of January. This not when the lowest summer flows occur (just when data stopped being collected). Percentage change in gauged tributary flows compare favourably to flows recorded at Gloucester Street (Table 3.6).

Figure 3.9 shows the hydrograph of the shallow watertable well measured at Kirkwood Intermediate School (Riccarton) from 1965 to 1993 (see figure 3.8 for well

Table 3.6 Comparison of Avon River System Flow Rates (l/s) Between 1973, 1980, 1985, 1992 & 1993

	January. 1973	March 1980 (CDB)	April 1985 (Daglish)	March 1992	January. 1993	% difference between March 1980 and April 1985	% difference between March 1980 and March1992	% difference between April 1985 and March1992	% difference between April 1985 and January 1993	% dfference between March 1980 and January 1993
Avon River @ Gloucester St	1886	2503*	1325	?	1925	53	50	?	145	77
Avon R. Trib @ railway bridge, Monavale or Harakeke St		780**	371	242^	548^	47	31	65	147	70
Waimairi Strm @ railway bridge, Monavale or Daresbury Park^		600**	339	214	414	56	36	63	122	69
Wairarapa Strm @ Fendalton Road or Garden Road		570**	411	260	645	72	45	63	156	113
Addington Drain @ Riccarton Av		50**		27	29		58			58
Riccarton Drain		102**		44	100		43			98
	Average total % difference in tributary contribution					58	43	64	142	82

* May 1980

** Gauging card not verified

^ Flow from Drain 23 added

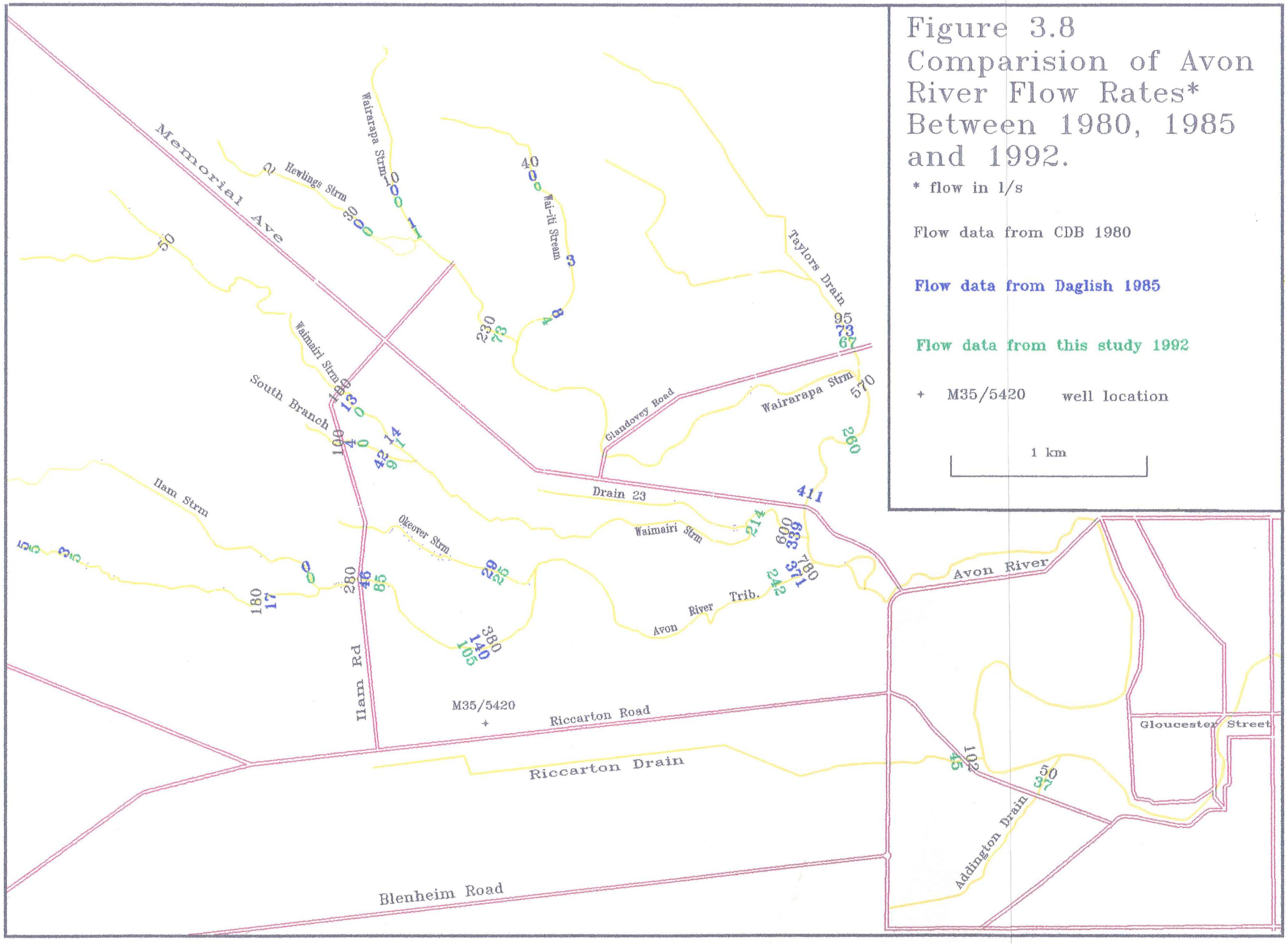


Figure 3.8
Comparision of Avon River Flow Rates* Between 1980, 1985 and 1992.
* flow in l/s
Flow data from CDB 1980
Flow data from Daglish 1985
Flow data from this study 1992
+ M35/5420 well location
1 km
Memorial Ave
Hewlings Strm
Wairarapa Strm
Wai-iti Stream
Taylors Drain
Waimairi Strm
South Branch
Glandovey Road
Wairarapa Strm
Drain 23
Ilam Strm
Okeover Strm
Waimairi Strm
Avon River
Avon River Trib.
Ilam Rd
M35/5420
Riccarton Road
Riccarton Drain
Blenheim Road
Gloucester Street
Addington Drain

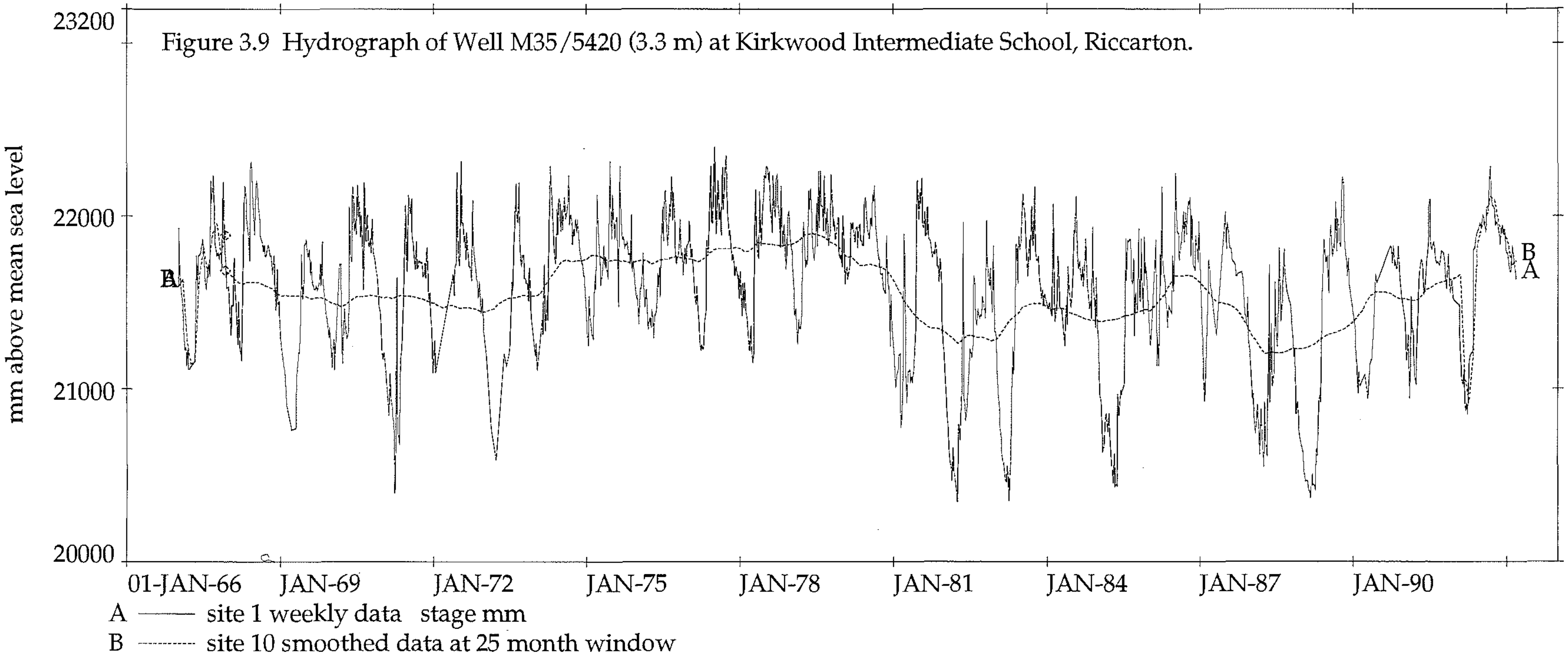


Figure 3.9 Hydrograph of Well M35/5420 (3.3 m) at Kirkwood Intermediate School, Riccarton.

location). The watertable in the summer of 1979-80, when CDB (1980) survey was conducted, was the highest summer level in the 25 year record. In the summer of 1984-85, when Daglish (1985) conducted his survey, groundwater levels were amongst the lowest on record. Hence, the relatively large difference in Avon River flow between these two periods is not surprising. However, watertable levels during the summer of 1991-92 were higher than in the summer of 1984-85 (Figure 3.9), but the stream flow in 1992 was 64% of that in 1985. This may suggest that the groundwater level measured at Kirkwood Intermediate is not indicative of groundwater levels in the northwestern area of the Avon catchment, and a decline in groundwater levels occurred in the northwestern catchment between 1980 and 1992. Post 1985 development of residential areas in the northwestern suburbs may have lowered the watertable in this area. Unfortunately, there are no shallow well records in this area for the period 1985-92. Anecdotal information from residents who have springs on their property confirm that a decline in spring flow was noticed when subdivisions were developed upstream of their properties. Springs in the South Branch Stream at 177 Ilam Road had noticeably less flow following the development of the subdivision adjacent to Blanc Park (pers. comm., Mr Hogdson, resident at 177 Ilam Road). Spring flow in the Waimairi Stream at 59 Greers Road declined after housing development occurred in the Avonhead (pers. comm., Mrs Moros, resident at 59 Greers Road). Similarly, historical springs on the Wai-iti Stream at 75 Brookside Terrace, Bryndwr, stopped flowing approximately 20 years ago when housing development occurred to the west (pers. comm., Mr Thwaits, resident at 55 Brookside Terrace).

3.4.4.2 Reduction in Contributing Channel Length

Daglish (1985) also noted that total contributing channel length had decreased between 1980 and 1985; headwater springs occurred downstream of their 1980 position. Figure 3.10 shows the position of headwater springs that were recorded by CDB (1980), Daglish (1985) and during this study in 1992-93. The data indicate that

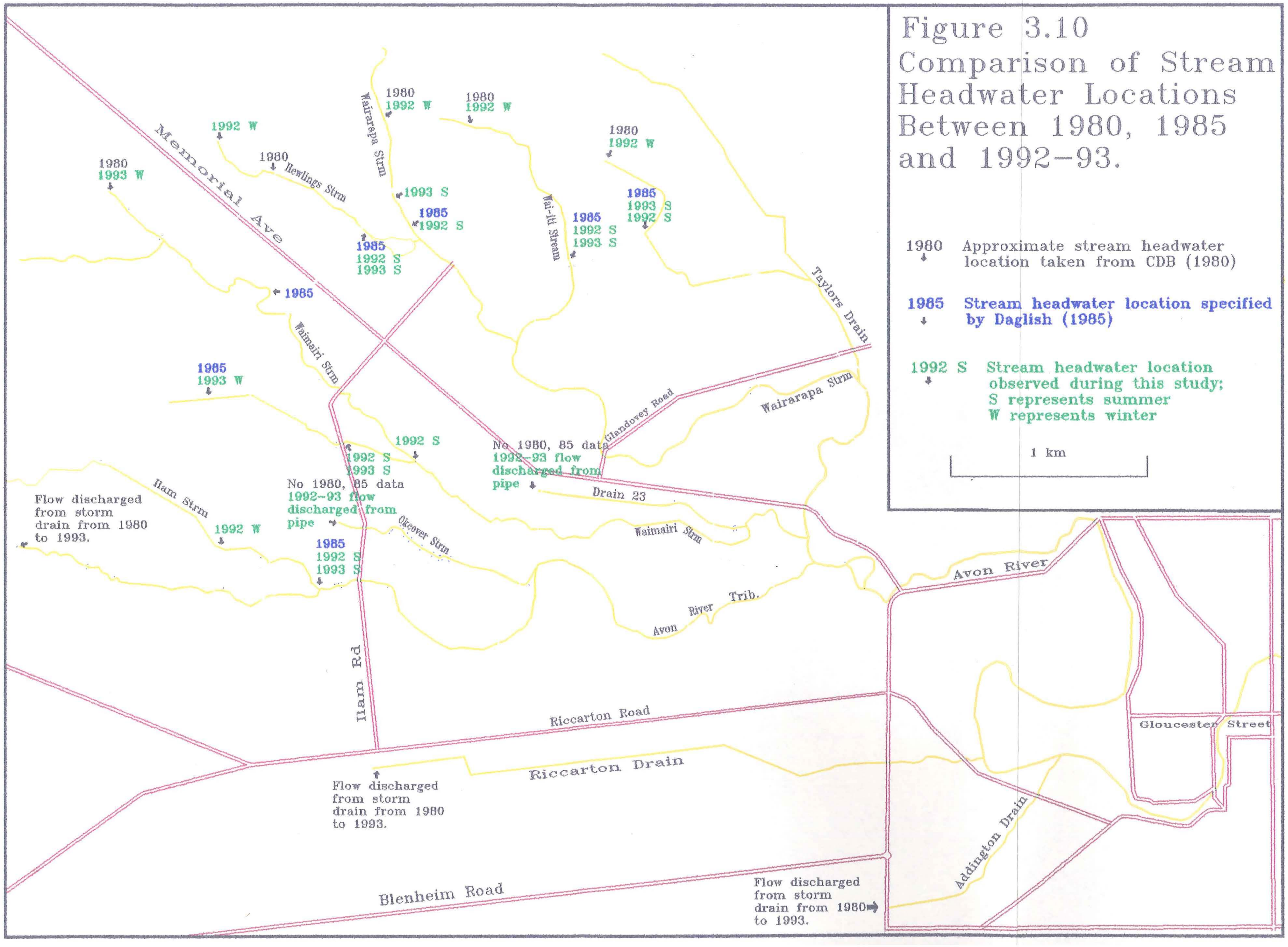


Figure 3.10
Comparison of Stream Headwater Locations Between 1980, 1985 and 1992-93.
1980 Approximate stream headwater location taken from CDB (1980)
1985 Stream headwater location specified by Daglish (1985)
1992 S Stream headwater location observed during this study; S represents summer W represents winter
1 km
Memorial Ave
Wairarapa Strm
Hewlings Strm
Wai-iti Stream
Taylors Drain
Waimairi Strm
Wairarapa Strm
Glandovey Road
Drain 23
Ilam Strm
Okeover Strm
Waimairi Strm
Avon River
Avon River Trib.
Ilam Rd
Riccarton Road
Riccarton Drain
Blenheim Road
Addington Drain
Gloucester Street
No 1980, 85 data 1992-93 flow discharged from pipe
No 1980, 85 data 1992-93 flow discharged from pipe
Flow discharged from storm drain from 1980 to 1993.
Flow discharged from storm drain from 1980 to 1993.
Flow discharged from storm drain from 1980 to 1993.

contributing channel length in some streams continued to declined from 1985 to 1992.

3.4.5 DIURNAL AND WEEKLY FLUCTUATIONS IN THE AVON RIVER RECORD

McCammon (1976) identified a close correlation between bore water level fluctuations and water use in the Christchurch area. Fluctuations also occur in response to soil moisture variations in the surface confining layer (ie rainfall increases the weight of the overlying soil). Diurnal changes in groundwater storage in unconfined aquifers have been related to evaporation and evapotranspiration (Ineson and Downing, 1964). Plants within a catchment, particularly along the riparian tract immediately adjacent to the river, that have root systems which extend into the capillary fringe and the zone of saturation will withdraw groundwater and in some cases stream water. The amount of water withdrawn by evapotranspiration will be a function of the type and density of vegetation, the depth to water table, and atmospheric conditions. Higher rates of evapotranspiration will occur during the summer than during the winter, and on hot dry days than on cool humid days.

Figure 3.11 shows the hydrograph of the watertable well M35/6772 at the University of Canterbury. The location of the well is appears in Figure 3.1. Short term cycles occur in the record in response to abstraction periods. A large drawdown occurs during weekdays when water is withdrawn for air-conditioning at the University. The large drawdown does not occur in the weekends when air conditioning is not used. A smaller drawdown occurs late every evening due to abstraction for irrigation on the campus. The variation in groundwater levels during the weekends may be due to evapotranspiration.

Figure 3.11 also shows Avon River flow at Gloucester Street (site 66602, Figure 3.1). The river weed growth has caused a smoothed stage to discharge relationship which is seen in the first six days of the flow data. The smallest scale "stepped" fluctuation in

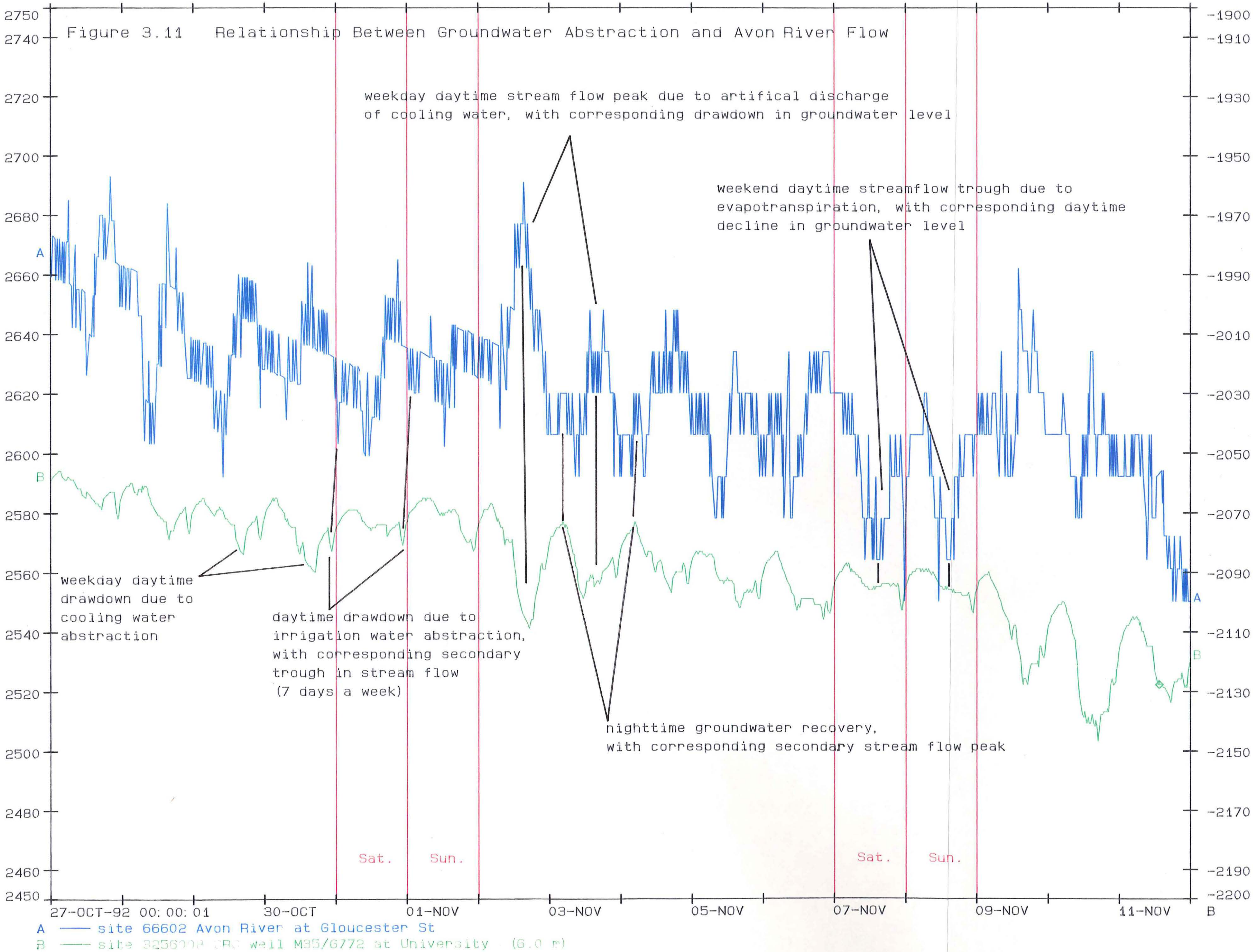


Figure 3.11 Relationship Between Groundwater Abstraction and Avon River Flow
2750
2740
2720
2700
2680
2660
2640
2620
2600
2580
2560
2540
2520
2500
2480
2460
2450
-1900
-1910
-1930
-1950
-1970
-1990
-2010
-2030
-2050
-2070
-2090
-2110
-2130
-2150
-2170
-2190
-2200
A
B
weekday daytime stream flow peak due to artifical discharge of cooling water, with corresponding drawdown in groundwater level
weekend daytime streamflow trough due to evapotranspiration, with corresponding daytime decline in groundwater level
weekday daytime drawdown due to cooling water abstraction
daytime drawdown due to irrigation water abstraction, with corresponding secondary trough in stream flow (7 days a week)
nighttime groundwater recovery, with corresponding secondary stream flow peak
Sat.
Sun.
Sat.
Sun.
27-OCT-92 00:00:01
30-OCT
01-NOV
03-NOV
05-NOV
07-NOV
09-NOV
11-NOV
A —— site 66602 Avon River at Gloucester St
B —— site well M35/6772 at University (6.0 m)

the flow record is due to the resolution of the recording instrument. For low flow levels, each step represents approximately 14 l/s change in flow.

During the weekdays peak flow occurs during the daytime when the groundwater that was withdrawn for air-conditioning is discharged into the river. The magnitude of fluctuations in flow in Figure 3.11 corresponds to the cooling water discharge into The Avon River Tributary and Okeover Stream from the University (see Appendix 2.1 for the river discharge from the University into the Avon River Tributary and Okeover Stream). During the weekend the river flow mirrors the groundwater level. In the weekends, no cooling water is discharged into the river, lowest flows occur during the daytime and peak flows at night. This study proposes that this is a result of evapotranspiration induced removal of water from the shallow watertable (and/or directly from the river) during the day with night time groundwater level recovery.

The effect of nightly groundwater level recovery during the week is also seen in the river flow record as a smaller secondary peak corresponding to the groundwater peaks.

CHAPTER 4 HYDROGEOLOGY OF THE AVON RIVER SYSTEM

4.1 INTRODUCTION

The near-surface sediments beneath the western tributaries of the Avon River contain late Holocene Waimakariri flood channel deposits, composed predominantly of gravel. The gravels are often bordered by finer overbank silts and sands. Interspersed between these alluvial sediments are areas of fine-grained swamp deposits. The surface swamp deposits that occur in the study area are predominantly Taitapu silt loam which typically has slow or very slow through drainage (Kear *et al.* 1969; NCCB 1986) (see Section 2.1.7).

Three-dimensional fence diagrams have been drawn through the shallow sediments beneath some areas of the Avon River catchment (Figure 4.1, 4.2 and 4.3). The fence diagrams were constructed using the closest available well logs to the stream channel. The correlation of gravel surfaces in the diagrams are tentative and are incorporated more to aid understanding than to correlate sediments. Well logs that were not included in the fence diagrams showed that correlation between wells only several tens of meters apart was often not possible. The classification of the sediment in the well logs was made at the time of drilling, most often by the well driller, so the sediment description is subjective and should not be regarded as definitive.

In the headwater reaches of the Avon River, groundwater was observed to enter the stream by two different processes. One process is through "artesian springs" that occur where the surface deposits are characterised by fine-grained sediments (i.e., silty sand, silt and/or clay) overlying water-bearing gravels. The relatively less permeable, fine sediment is thought to act as a "semi-confining" layer that facilitates the development of an artesian head in the underlying gravel aquifer. Artesian spring flow would then occur through "pipes" in the fine sediment and discharge into the stream through vents in the stream bed (Figure 4. 4). A second process by which

Figure 4.1 Three-Dimensional Fence Diagram of the Avon River Tributary Showing the Near-Surface Geology, and Locations of Artesian Springs and Groundwater Seepage Through Stream Bed Gravels

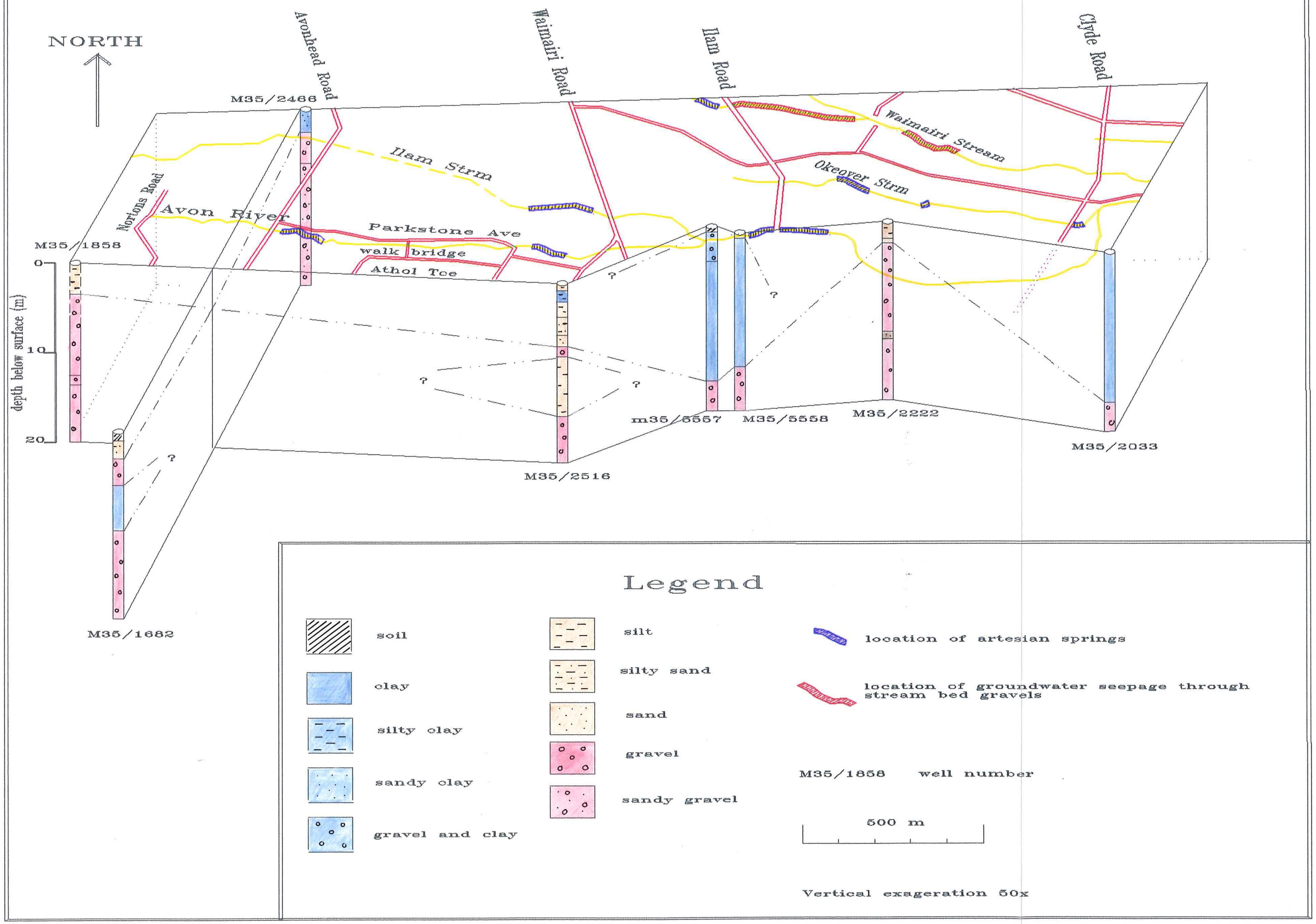
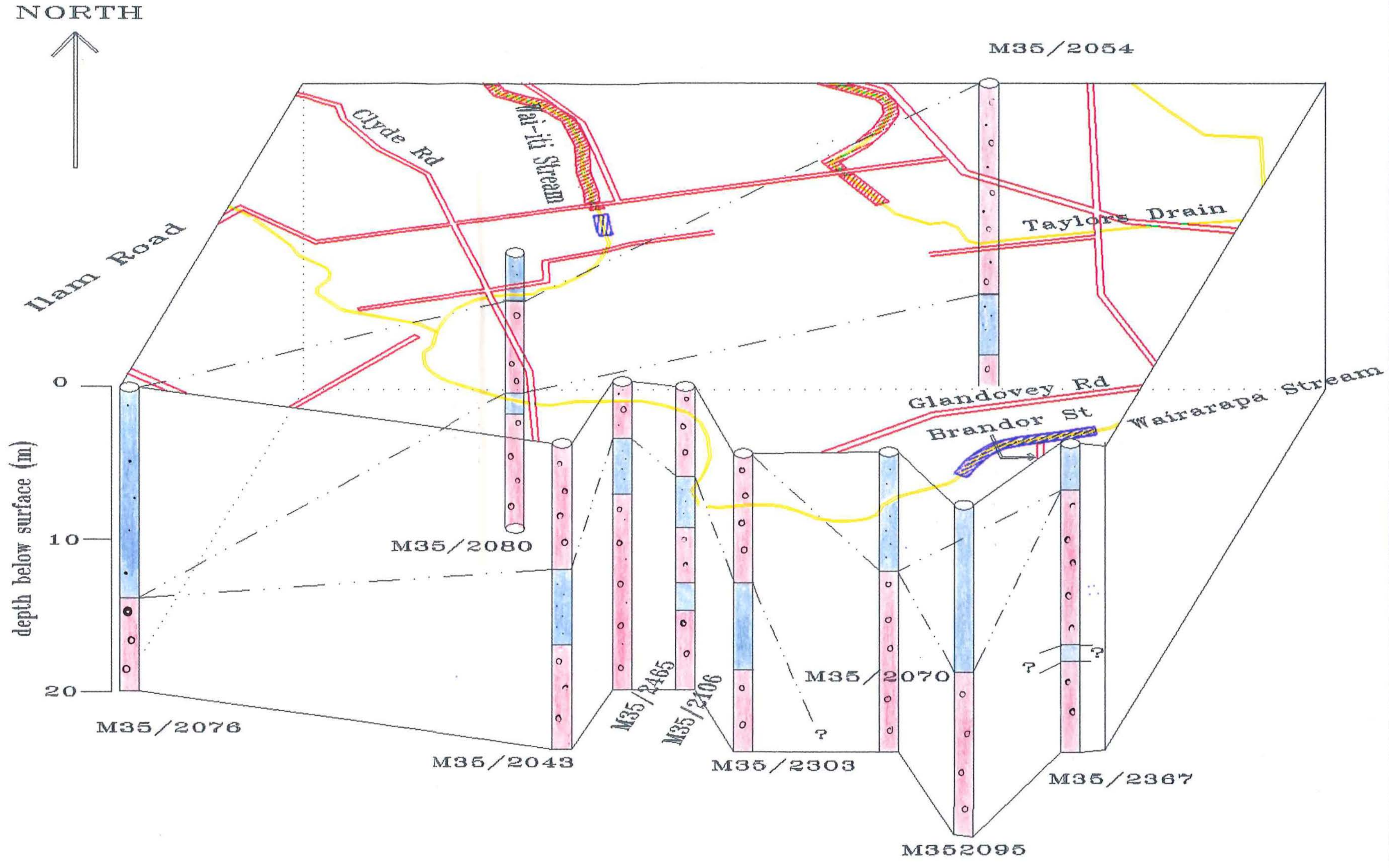


Figure 4.2 Three-Dimensional Fence Diagram of the Wairarapa Stream Showing the Near-Surface Geology, and Locations of Artesian Springs and Groundwater Seepage Through Gravel



Legend

clay

sandy clay

sand

sandy gravel

gravel

location of artesian springs

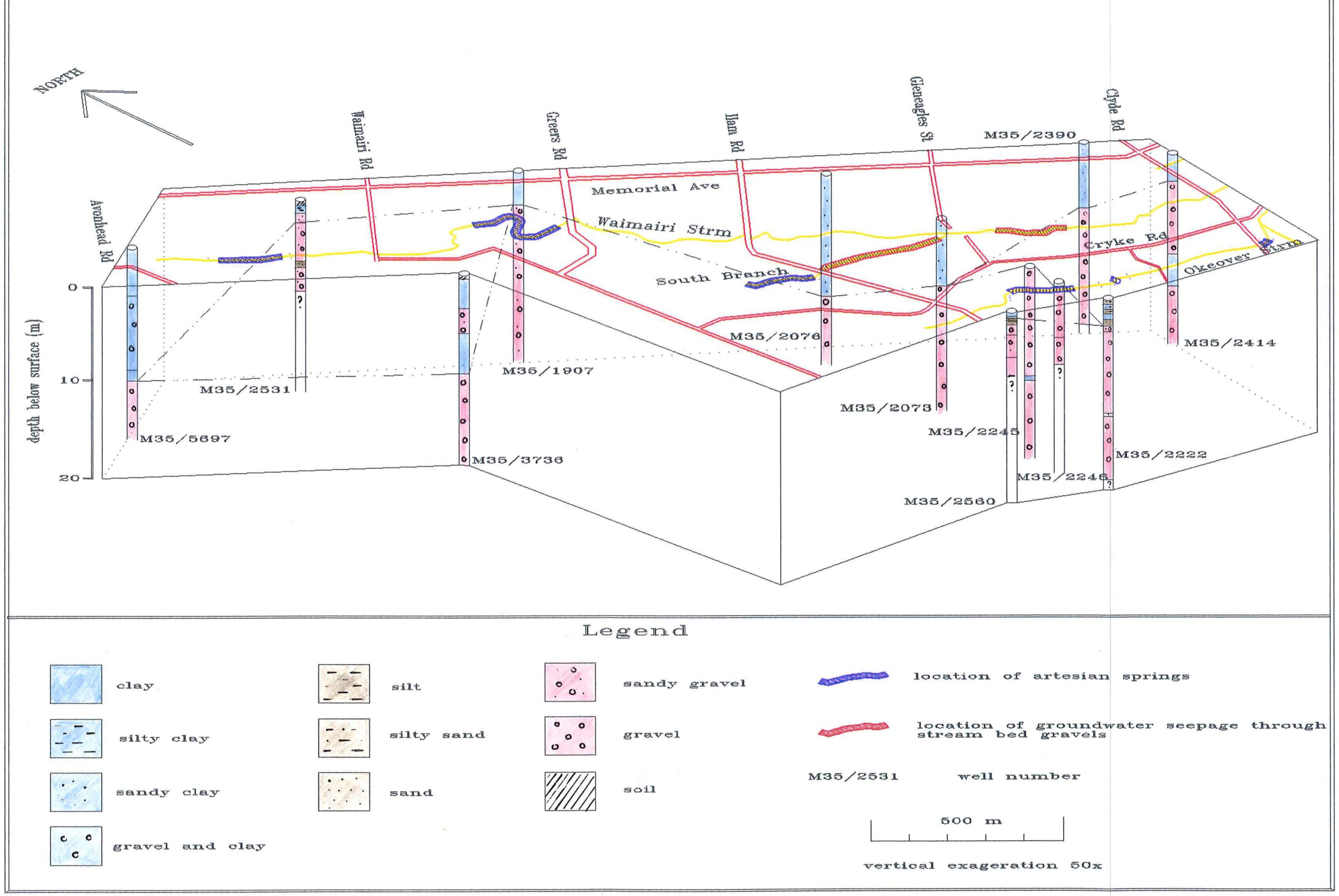
location of groundwater seepage through stream bed gravels

M35/2567 well number

500 m

vertical exageration 50x

Figure 4. 3 Three-Dimensional Fence Diagram of the Waimairi Stream Showing the Near-Surface Geology, and Locations of Artesian Springs and Groundwater Seepage Through Stream Bed Gravels



groundwater was observed to enter the stream was by "groundwater seepage through stream bed gravels". The proposed models of these two processes are presented in Section 4.3.

An "Artesian spring" is defined for the purpose of this study as water which issues under pressure through some "fissure" of other opening in a confining formation that overlies an aquifer (Schieferdecker 1959). In the Avon River, discharge from artesian springs was often evident by the disturbance of the stream surface caused by the spring discharge (Figure 4.4), or by the presence of suspended sediment in the artesian spring water. The "fissure" is hereafter referred to as a "pipe" as it is believed by the author that this is a more accurate term for this soft sediment structure.

The suspended sediment in the water discharging from a spring was only observed at the early stages of spring vent development. The occurrence of suspended sediment in the spring discharge stopped after a period of time. Presumably this was when the pipe that connects the spring vent to the underlying water-bearing gravels had developed to a size that was a function of the flow rate through the pipe.

In contrast, where groundwater entered the stream by seepage through stream bed gravels, the groundwater discharge was at such a low rate that its flow was not observable, but stream flow increased progressively downstream. This type of groundwater contribution to streamflow could be likened to Schieferdecker's (1959) "channel spring", which was defined as a spring that occurs in a stream which has cut a channel below the watertable. However, for the sake of clarity, it will be referred to in this study as "groundwater seepage through gravel".

On the basis of several hundred well logs, the C.R.C. has constructed contour maps of the depth below surface of the gravel deposits (Figure 4.5). In the construction of these contours, interpolation between well logs was necessary and the position of the

Figure 4.4 Artesian Spring on Avon River Tibutary located approximately 100 m upstream of Corfe Street - Parkstone Avenue walk bridge. Note spring vent.

contours are therefore approximate. Figure 4.5 shows the approximate positions of gravels that are within 1 m of the land surface, 1 to 5 m below the land surface, and 5 to 10 m below the land surface. The overlying sediments are the finer-grained sands, silts and clays of the overbank and swamp deposits. Groundwater seepage through streambed gravel occurs within and near the 1 m gravel contour. In these localities, the stream channel intersected the shallow gravel deposits. Artesian springs were observed where gravels were within approximately 1 to 10 m of the land surface. Where the depth to gravel exceeded approximately 10 m, no artesian springs were observed.

4.2 SPATIAL RELATIONSHIP BETWEEN THE SHALLOW GEOLOGY AND THE PROCESS OF GROUNDWATER DISCHARGE INTO THE AVON RIVER SYSTEM

The three-dimensional fence diagrams show, as suggested, that artesian springs occur where gravels are overlain by less than approximately 10 m of finer grained silty sand, silt and/or clay (Figures 4.1, 4. 2 and 4.3). Large spring vents, up to 0.3 m in diameter, were observed in stream sections where the fine sediments immediately underlying the stream bed were between approximately 3.5 m and 10 m thick (Figure 4.4). Where the thickness of the fine surface sediments was only several meters thick, artesian spring vent size and discharge were considerably less. This may be due to the increased hydraulic head with depth that occurs in the groundwater system beneath Christchurch. The fence diagrams confirmed that headwater gravel seepage occurs in stream sections immediately underlain by gravels.

4.2.1 HYDROGEOLOGY OF THE GROUNDWATER DISCHARGE INTO THE AVON RIVER TRIBUTARY

Figure 4.1 shows the near surface sediments that underlie the Avon River Tributary between Clyde Road and Nortons Road. Artesian springs occur in the stream section in the vicinity of Ilam Road. The well log from M35/5560 indicates that the upstream limit of these springs coincides with a 15 m thick clay surface deposit. The clay deposit appears to inhibit the development of artesian springs. Downstream of Clyde Road, the depth to gravel decreases, and artesian springs become less frequent

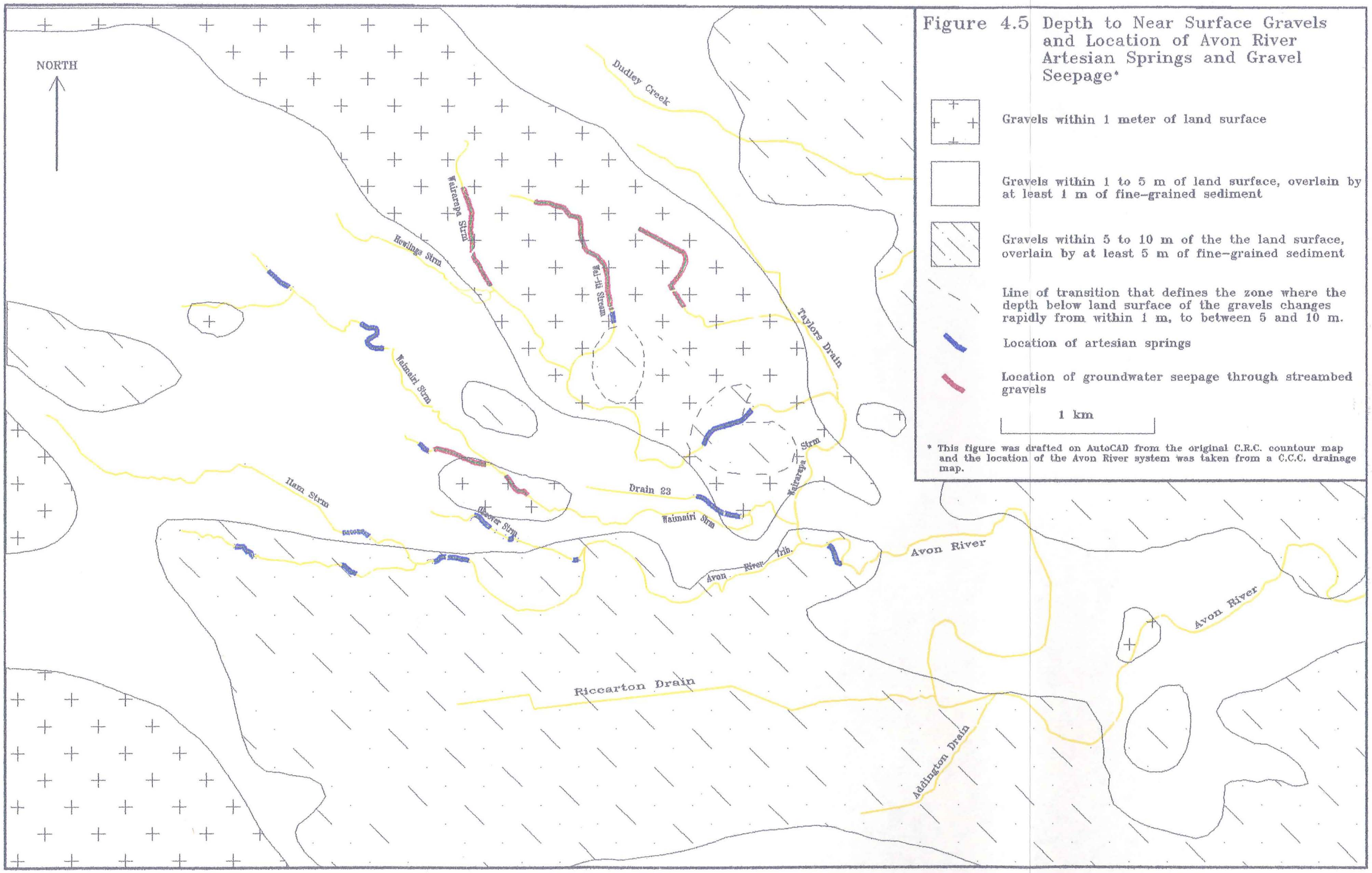


Figure 4.5 Depth to Near Surface Gravels and Location of Avon River Artesian Springs and Gravel Seepage*

* This figure was drafted on AutoCAD from the original C.R.C. countour map and the location of the Avon River system was taken from a C.C.C. drainage map.

and eventually cease to occur as the stream bed sediment grades to predominantly gravel. Artesian springs also occur in the silt bottomed section of stream between Waimairi Road and Parkstone Avenue. The well log from bore M35/2516 shows that the depth to gravel decreases in this area and the overlying fine sediments are silty sand, silt and silty clay. No artesian springs were observed between Parkstone Avenue and the Parkstone Avenue-Corfe Street walk bridge, and lack of logged wells in this vicinity precludes the determination of the reasons for this absence. Artesian springs occur in the silt channel sediments upstream of the walk bridge where the gravel sediments are approximately 5 m below the surface (from tentative correlation of the gravel surfaces between well logs).

4.2.2 HYDROGEOLOGY OF THE GROUNDWATER DISCHARGE INTO THE WAIRARAPA STREAM

Figure 4.2 shows the near surface sediments beneath the Wairarapa Stream. Springs occur in the stream section at the northern end of Brandor Street. These springs coincide with an isolated surface outcrop of fine grained sediments that are approximately 5 to 10 m thick (Figure 4.5). Small artesian springs occur in Wai-iti Stream, 50 m downstream of Ilam Road. In the vicinity of this stream section an isolated surface outcrop (approximately 1 to 2 m thick) of silt and clay overlies gravel. From field observations, the stream bed sediment both upstream and downstream of this section was gravel. This change in stream bed sediment is also seen in the bore logs used in the construction of the fence diagram. In the headwaters of the Wairarapa Stream, and in the Wai-iti Stream upstream of Ilam Road, stream flow begins by seepage through gravel. Figure 4.5 shows that the surface gravels which are present in the upper reaches of the Wai-iti and Wairarapa streams, continue westward beyond the study area. These gravels represent a historical Waimakariri flood channel (Brown and Weeber 1992).

4.2.3 HYDROGEOLOGY OF THE GROUNDWATER DISCHARGE INTO THE WAIMAIRI STREAM

The lack of logged wells close to the Waimairi Stream channel restricts the construction of an informative three-dimensional fence diagram for this area (Figure 4.3). Although the stratigraphy of the near-surface sediments in the immediate vicinity of the stream channel is not defined by the available well logs, the well log data in Figure 4.3 does not contradict previous observations.

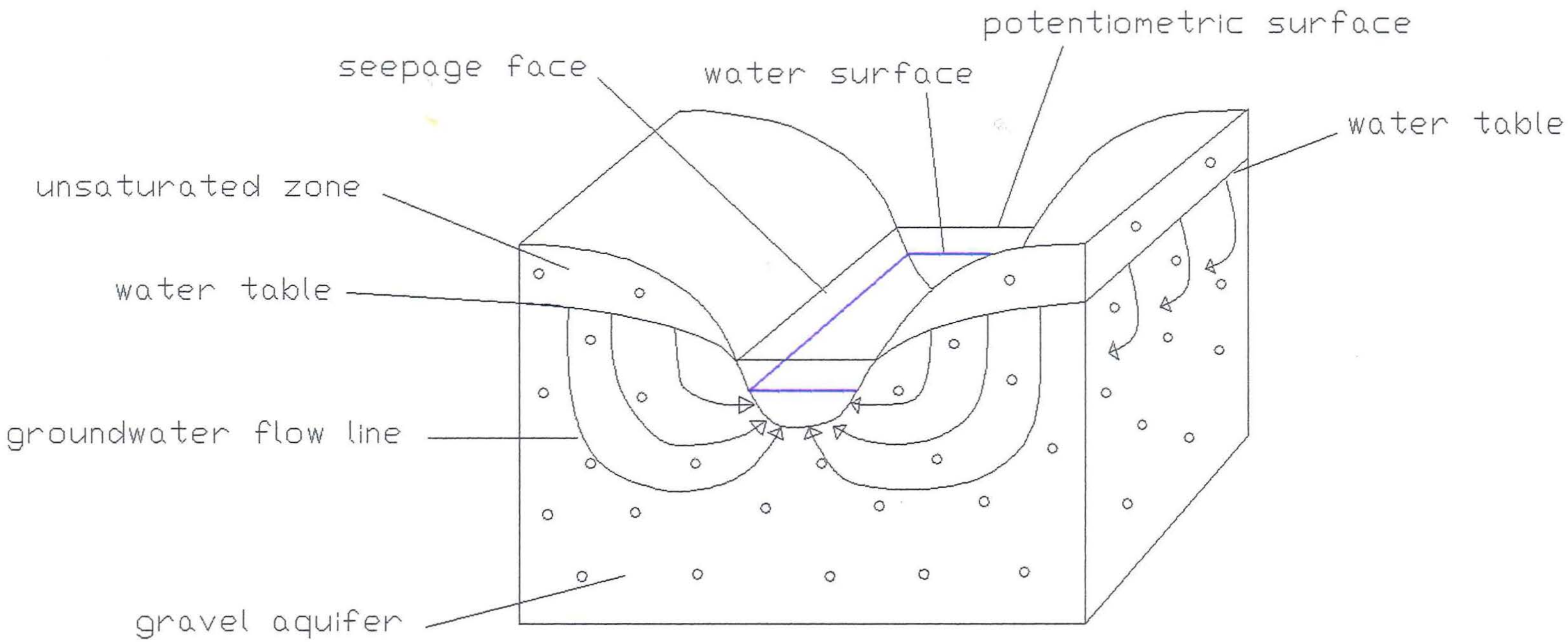
Groundwater seepage through stream bed gravels was observed in the lower reaches of the South Branch Stream and in the Waimairi Stream, between 100 and 300 m downstream of the South Branch Stream confluence. The field observations are supported by the well log data from M35/2245 and M35/2073 which indicate that the depth to gravel decreases in this area. Upstream, artesian springs were present in the South Branch Stream and Waimairi Stream west of Ilam Road and Greers Road, respectively. Well logs indicate that the thickness of the fine-grained surface sediment increases in this direction.

Small artesian springs occur in two sections of the Okeover Stream as it flows through the University campus. The logs of wells M35/2222 and M35/2560 indicate that a thin veneer of fine-grained surface sediment overlies gravel in areas proximal to Okeover Stream artesian spring sections.

4.3 PROPOSED MODELS OF THE GROUNDWATER DISCHARGE INTO THE AVON RIVER SYSTEM

Figure 4.6 is a schematic diagram showing the process by which groundwater is thought to enter the stream by seepage through stream bed gravels. Stream flow is augmented by groundwater entering the stream through the seepage face. In plan view all groundwater flow lines are directed towards the stream. The quantity of flow between the aquifer and the stream is dependent on the difference in the hydraulic head between the stream and in the aquifer beneath the stream bed (potentiometric surface). In reality, the quantity of flow is also a function of bank

Figure 4.6 Groundwater - Streamflow in a watertable aquifer (adapted from Jorgensen et. al., 1986)



Groundwater flow into the stream is due to the difference in hydraulic head between the water surface in the stream and the potentimetric surface in the aquifer beneath the streambed.

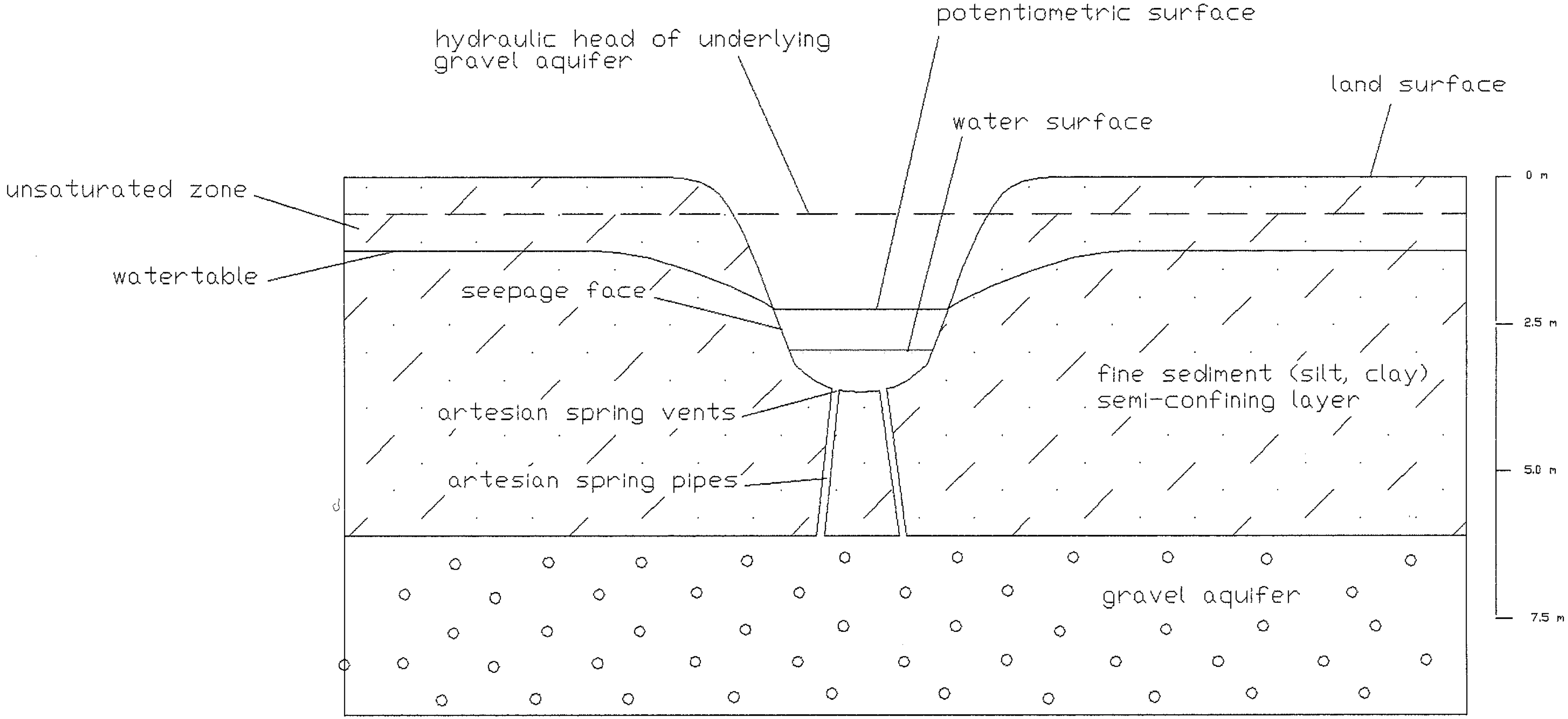
storage, hydraulic properties of the aquifer and hydraulic properties of the material connecting the aquifer and the stream (Jorgensen *et al.* 1989).

As mentioned, artesian springs were found to closely coincide with areas where gravels were overlain by approximately 1 to 10 m of finer sediment. Where the depth to gravel exceeded approximately 10 m, no artesian springs were observed. Figure 4.7 shows the model favoured for flow between the aquifer and the stream via artesian springs. In the model, streamflow is augmented by artesian springs that derive their groundwater from the underlying "semi-confined" gravel aquifer. The groundwater flows through "pipes" in the overlying finer sediments. For artesian spring flow to occur, the hydraulic head of the gravel aquifer must be higher than the stream water surface, otherwise the direction of flow will be from the stream to the underlying gravel. Where the thickness or the composition of the overlying fine-grained material is such that the hydraulic head of the underlying gravel aquifer is insufficient to develop "pipes", artesian springs will not occur.

If the model is applied to the Avon River, then in those stream sections where gravel seepage or artesian springs were not observed, groundwater would still enter the stream where the potentiometric surface is above the stream water surface. This is supported by the fact that flow in the Avon River tributaries was measured to increase downstream in sections where no groundwater input was observed (e.g., in the Avon River Tributary between Clyde Road and Harakeke Street; see Section 3.3.1).

The diameter of the vents varied from several millimetres to up to 0.3 m. The vents typically occurred in swarms, with up to several dozen being present in an artesian spring section of the stream. The number of vents in a stream section, and the diameter of the vents, progressively increased from March-April 1992, when groundwater levels and streamflow were at a minimum for the study period, to September-October 1992, when the groundwater levels and streamflow were at a

Figure 4.7 Proposed Model of Avon River Artesian Springs



maximum. The size of a vent seems to be a function of both the vents discharge and of the depth to underlying gravel (i.e., artesian spring discharge increased with vent size and larger vents occurred with a greater depth to underlying gravel). However, where the well logs showed that depth to gravel exceeded 10 m, no Artesian springs were observed. This implies that there is a maximum depth to gravel (approximately 10 m) beyond which artesian springs cannot develop. This is supported by the fact that in the Avon River Tributary, artesian springs stopped occurring in the stream channel adjacent to well M35/5660 (Figure 4.1), which well log indicates that the depth to gravel had increased in this area to approximately
15 m.

Further work could be carried out to define more accurately the thickness of overlying sediment that is associated with artesian spring occurrence. The depth of incision of the Avon River channel varies throughout the catchment from less than 1m to approximately 4 m. If the depth of stream channel incision at artesian spring locations is considered, then the maximum thickness of fine-grained surface sediment beyond which artesian springs do not occur may be less than approximately 10 m.

CHAPTER 5 THE RELATIONSHIP BETWEEN AVON RIVER STREAM FLOW AND SHALLOW GROUNDWATER LEVELS

5.1 INTRODUCTION

The two models (presented in Chapter 4) of the mechanisms by which groundwater is thought to enter the Avon River system imply that baseflow is supplied directly from both the watertable aquifer and from the uppermost confined aquifer (Aquifer 1). Shallow groundwater is defined then, for the purposes of this study, as the groundwater that occurs in the watertable aquifer and in Aquifer 1.

Watertable levels in the study area increased in response to rainfall events. Section 5.2 of this chapter briefly discusses the response of groundwater levels in watertable well M35/6772 to a rainfall event. It was known prior to this study that the Avon River headwater spring positions migrated, and that baseflow fluctuated, in response to seasonal and longer term variations in shallow groundwater levels (Daglish 1985; NCCB 1986). The migration of headwater spring positions that occurred during the study period is discussed previously (Section 3.4.4.2). The variation in the Avon River system's baseflow that resulted from the seasonal fluctuation in shallow groundwater levels during the study period is discussed in Section 5.3 where the relationship between baseflow and groundwater levels is defined by simple linear regression analysis.

Regression analysis of the baseflow and groundwater level data was carried out on the software package SAS. Data was merged using the editing facilities in TIDEDA, with groundwater data interpolated between data points to obtain corresponding times for stream flow and groundwater levels. An error will be incorporated in the analysis as a result of this interpolation. Baseflow data and groundwater level data that were collected during this study and used in the regression analysis appear in

Appendices 3.2 to 3.14 and 5.1, respectively. The baseflow record of the Avon River at Gloucester Street and the historical groundwater data is held on the VAX system at the C.R.C.

5.2. WATERTABLE RESPONSE TO RAINFALL IN THE AVON RIVER CATCHMENT

Rain falling on the Avon River catchment either evaporates, is discharged into the Estuary by the Avon River drainage system, or infiltrates to recharge the shallow groundwater. The upwards hydraulic gradient in the coastal region is thought to prevent recharge of the deeper confined aquifers by the infiltration of local rainfall (NCCB 1986) (Figure 2.7, Chapter 2). The peak in groundwater hydrographs of bores that tap the deeper confined aquifers following a rainfall event are postulated to be due to a pressure response caused by the increase in surface weight from the rainfall (McCammon 1976).

Figure 5.1 shows the hydrograph of Well M35/6772, located in the University of Canterbury campus, Ilam. The location of this well is shown in Figure 5.2. The large rise in hydrostatic head is considered likely to be caused by air entrapment in the unsaturated zone. An anomalously large rise in hydrostatic head is known to occur when rainfall infiltration creates an inverted zone of saturation at the ground surface and the advancing wet front traps air between it and the watertable. Air pressure in this zone can build up to a value much greater than atmospheric. The most characteristic features of a groundwater hydrograph rise in response to air entrapment are the magnitude of the ratio of water-level rise to rainfall depth and the rapid dissipation of the rise. The anomalous rise usually dissipates within a few hours owing to the lateral escape of trapped air (Freeze and Cherry 1979; Todd 1970), although there is still a residual increase in water level once the effects of air entrapment have dissipated (Figure 5.1).

An increase in the shallow groundwater levels was observed throughout the study area after the large rainfall events of late August-September 1992 (see Figure 5.7).

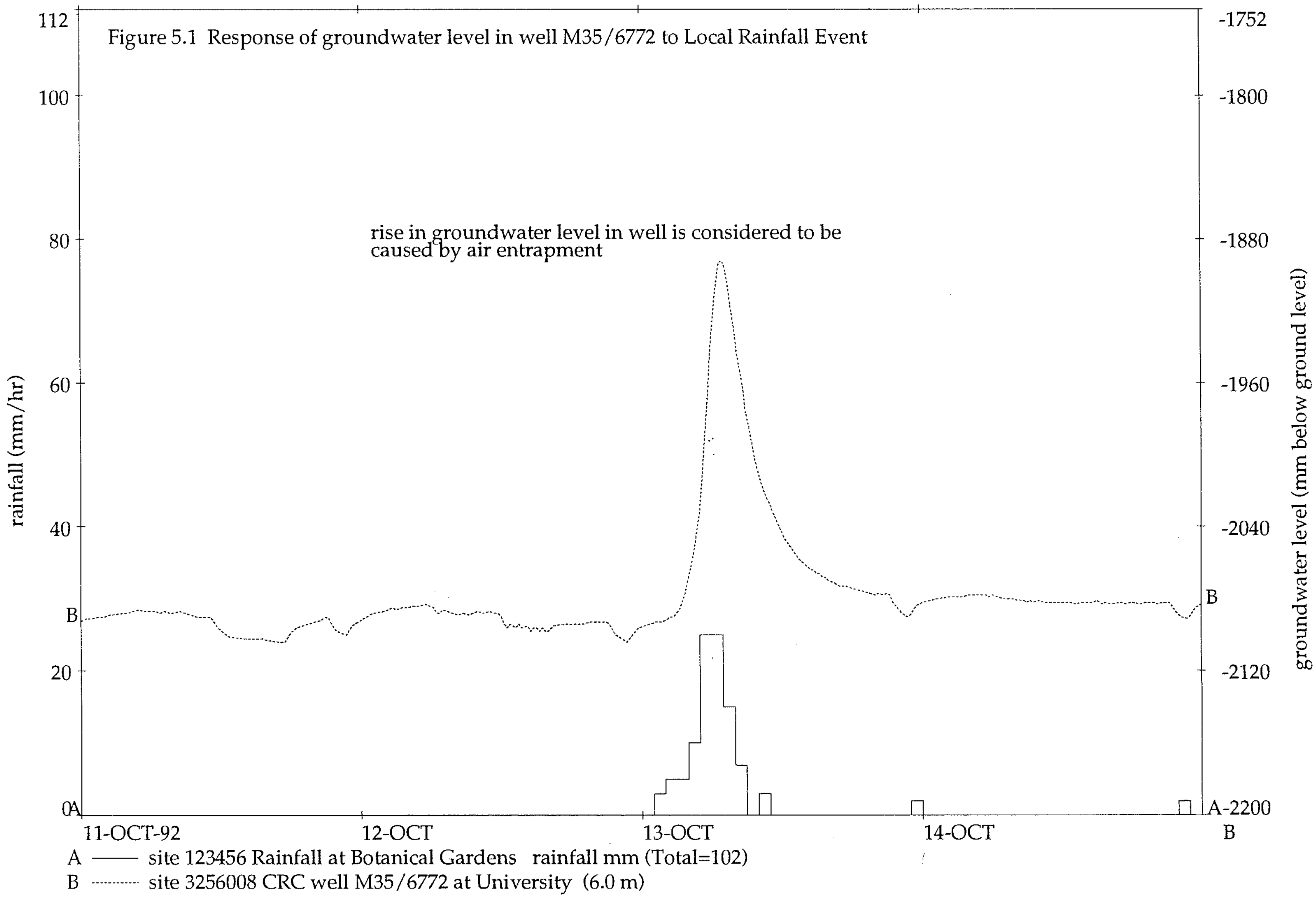


Figure 5.1 Response of groundwater level in well M35/6772 to Local Rainfall Event
rise in groundwater level in well is considered to be caused by air entrapment
rainfall (mm/hr)
groundwater level (mm below ground level)
112
100
80
60
40
20
0
-1752
-1800
-1880
-1960
-2040
-2120
-2200
A
B
11-OCT-92
12-OCT
13-OCT
14-OCT
A —— site 123456 Rainfall at Botanical Gardens rainfall mm (Total=102)
B ········ site 3256008 CRC well M35/6772 at University (6.0 m)

5.3 SHALLOW GROUNDWATER LEVELS AND THE BASEFLOW OF THE AVON RIVER SYSTEM

Although there are thousands of wells in the Christchurch area, the majority of these are relatively deep wells that tap the confined aquifers. In this study, analysis of the relationship between shallow groundwater levels and Avon River baseflow was restricted by the relatively sparse distribution of suitable shallow groundwater wells. The number of suitably located shallow wells that were of sufficient depth to intersect the watertable throughout the study period, that had not been filled in or built over, and that had obliging owners, numbered 15. Of these, eleven were monitored. The remaining four shallow wells were not monitored because of their very close proximity to other monitored wells. The position of monitored wells, stream gauging sites and rainfall stations are shown in Figure 5.2. The only watertable well within the study area which has had water levels recorded for any significant duration is well M35/5420 at Kirkwood Intermediate School, Riccarton. This well is located in the southwestern corner of the Avon River catchment. Groundwater levels in this well are measured weekly by the C.C.C.. In August 1992, the C.R.C. installed an automatic recorder on a shallow (6 m deep) watertable well (M35/6772) in the University of Canterbury Campus. This provided an excellent record of the watertable response to large rainfall events that occurred in late August-September 1992.

5.3.1 SHALLOW GROUNDWATER LEVELS AND AVON RIVER BASEFLOW (at Gloucester Street)

Figure 5.3 is a plot of daily rainfall totals at Botanical Gardens, the hydrographs of Avon River baseflow, and groundwater levels in three bores located within the study area that tap the watertable aquifer (M35/6772), Aquifer 1 (M35/5560), and Aquifer 2 (M35/2564). The plot shows that similar trends occur between Avon River baseflow and the hydrostatic head of the two uppermost confined aquifers and watertable level. Groundwater levels in the three wells are recorded automatically at 15 minute intervals. As noted above, the large rise in hydrostatic head following rainfall events is considered to be caused by a pressure response due to surface

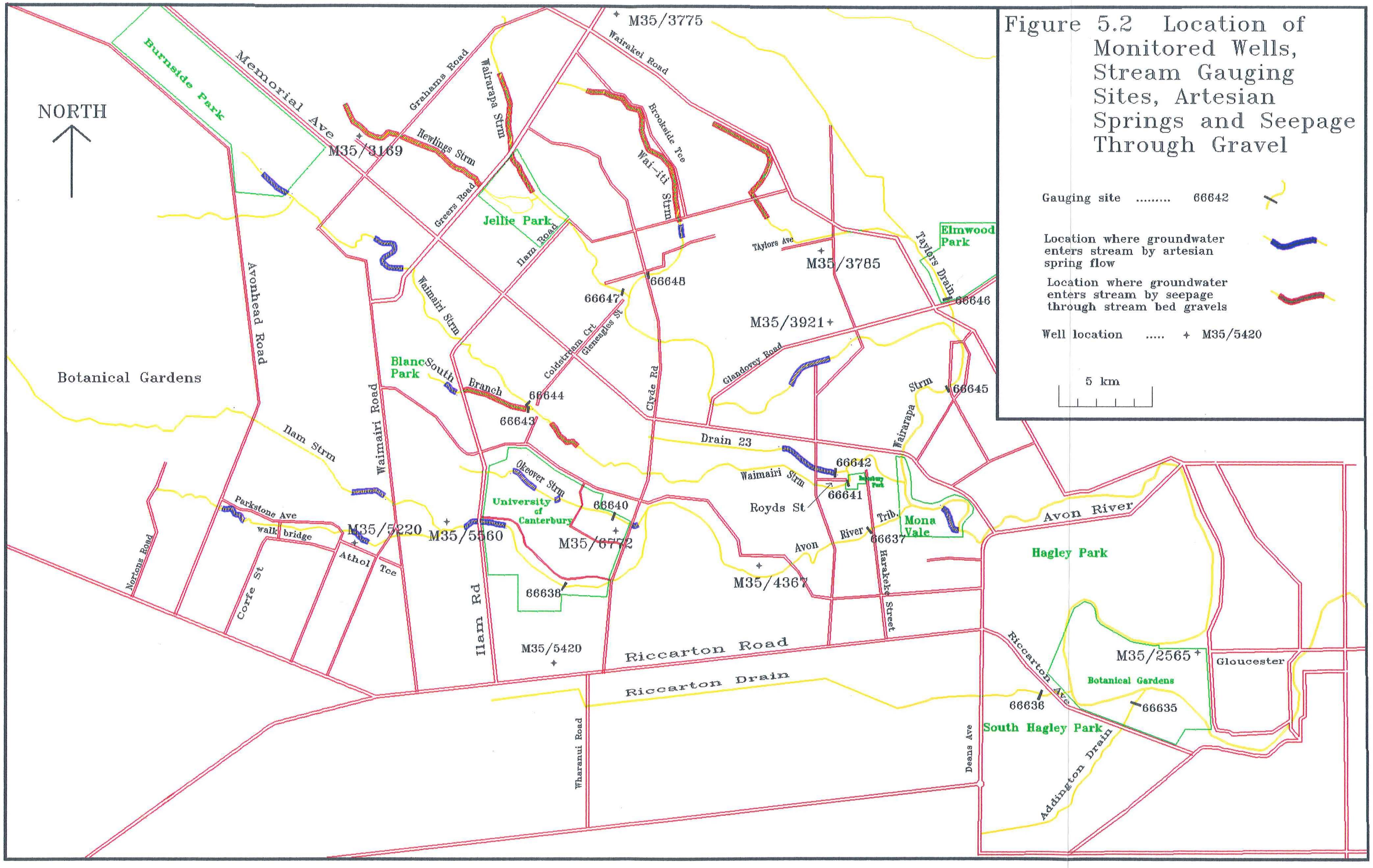


Figure 5.2 Location of Monitored Wells, Stream Gauging Sites, Artesian Springs and Seepage Through Gravel
Gauging site 66642
Location where groundwater enters stream by artesian spring flow
Location where groundwater enters stream by seepage through stream bed gravels
Well location ..... + M35/5420
5 km
NORTH
Botanical Gardens
Burnside Park
Memorial Ave
Grahams Road
Wairarapa Strm
Wairakei Road
M35/3775
Brookside Tce
Wai-iti Strm
M35/3169
Hewlings Strm
Greers Road
Jellie Park
Ilam Road
Avonhead Road
Waimairi Strm
Taylors Ave
M35/3785
Taylors Drain
Elmwood Park
66646
66648
66647
M35/3921
Coldstream Crt
Gleneagles St
Glandovey Road
Clyde Rd
Blanc Park
South Branch
66644
66643
Strm
66645
Wairarapa
Waimairi Road
Ilam Strm
Drain 23
66642
Waimairi Strm
66641
Royds St
Okeover Strm
University of Canterbury
66640
Parkstone Ave
walk bridge
M35/5220
M35/5560
M35/6772
Avon River
Trib.
Mona Vale
66637
Avon
Hagley Park
Nortons Road
Corfe St
Athol Tce
Ilam Rd
66638
M35/4367
Harakeke Street
M35/5420
Riccarton Road
Riccarton Drain
Wharanui Road
Deans Ave
Riccarton Ave
66636
M35/2565
Botanical Gardens
Gloucester
66635
South Hagley Park
Addington Drain

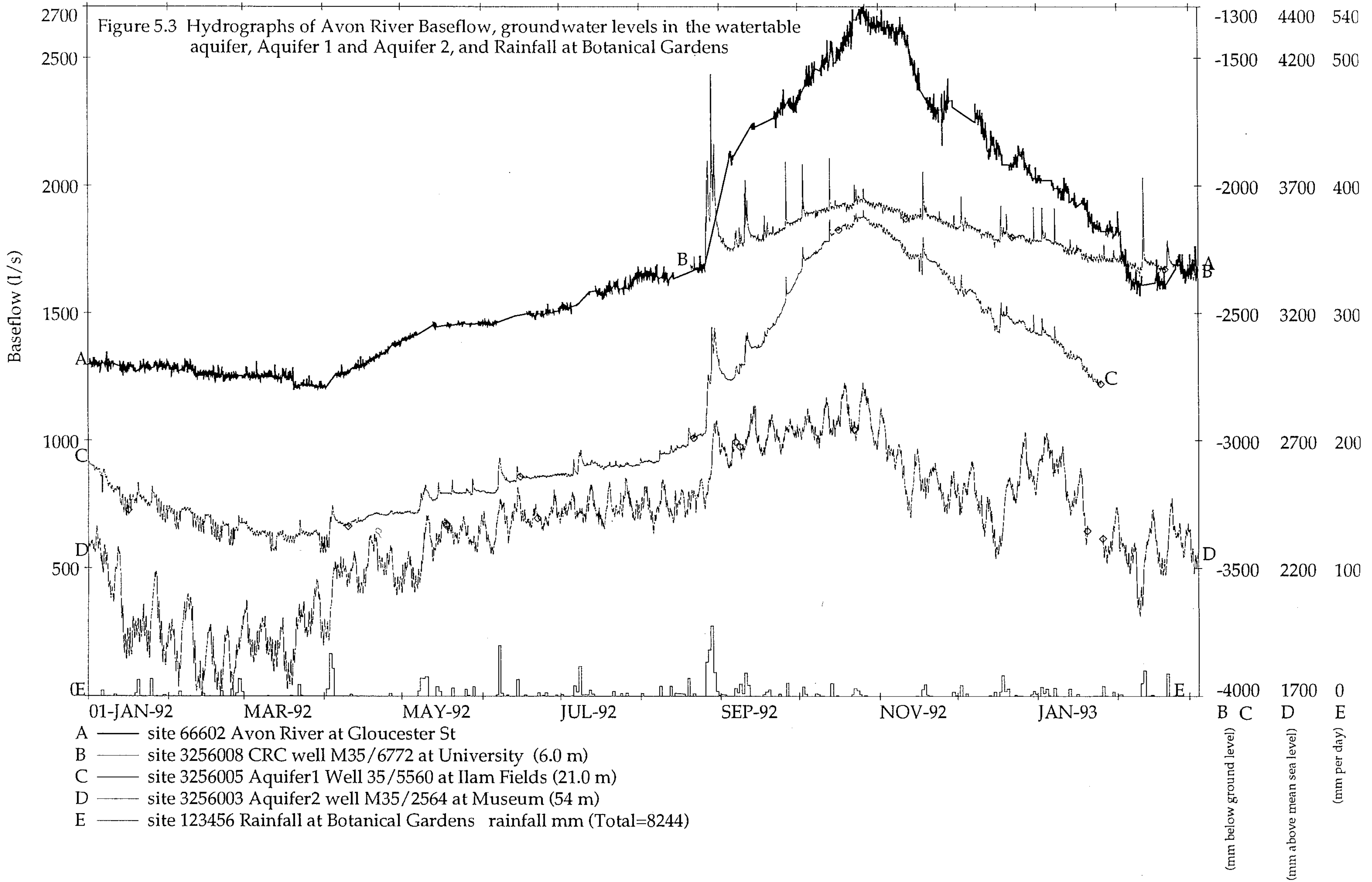


Figure 5.3 Hydrographs of Avon River Baseflow, groundwater levels in the watertable aquifer, Aquifer 1 and Aquifer 2, and Rainfall at Botanical Gardens

loading in the confined aquifers (McCammon 1976), and by air entrapment in the watertable aquifer (Section 5.2).

Critically low rates of Avon River baseflow occurred during the summer of 1991-92, with the minimum mean monthly baseflow (1239 l/s) occurring in March 1992 (Figure 5.3 and Table 3.5). The hydrographs of wells M35/5560 and M35/2564 show that measured groundwater levels in these wells were also at the minimum in March (Figure 5.3). The large rainfall events in late-August were followed by a significant increase in both the groundwater levels measured in shallow wells and Avon River baseflow (Figure 5.3). The August 1992 rainfall total recorded at Botanical Gardens was 197 mm. This is the highest monthly rainfall total recorded at this station since 1980, when the monthly rainfall data available to this study begins.

Figure 5.4 is a more detailed plot showing the period in which maximum groundwater levels and Avon River baseflow occurred in Figure 5.3. Groundwater levels continued to rise until the period approximately 24 October to 27 October, and then declined for the remainder of the study period. Figure 5.4 indicates that there was essentially no delay between the peak groundwater levels measured in wells M35/5560 and M35/6772, and the peak in Avon River baseflow recorded at Gloucester Street. The decline from the maximum groundwater levels and baseflow rates coincides with an 18 day period between 27 October and 15 November when no rainfall was recorded at Botanical Gardens (Figure 5.4). The apparent anti-correlation that occurs between the baseflow and groundwater hydrographs at a daily interval is caused by abstracted groundwater being discharged into the Avon River Tributary. This was discussed previously in section 3.4.5.

Figures 5.5 and 5.6 show the regression lines through the daily means of Avon River baseflow and the groundwater levels measured in wells M35/6772 and M35/5560, respectively. Using daily mean data will reduce the effect of the groundwater

Figure 5.4 Hydrograph of Seasonal Peak in Avon River Baseflow, and Shallow Groundwater Levels

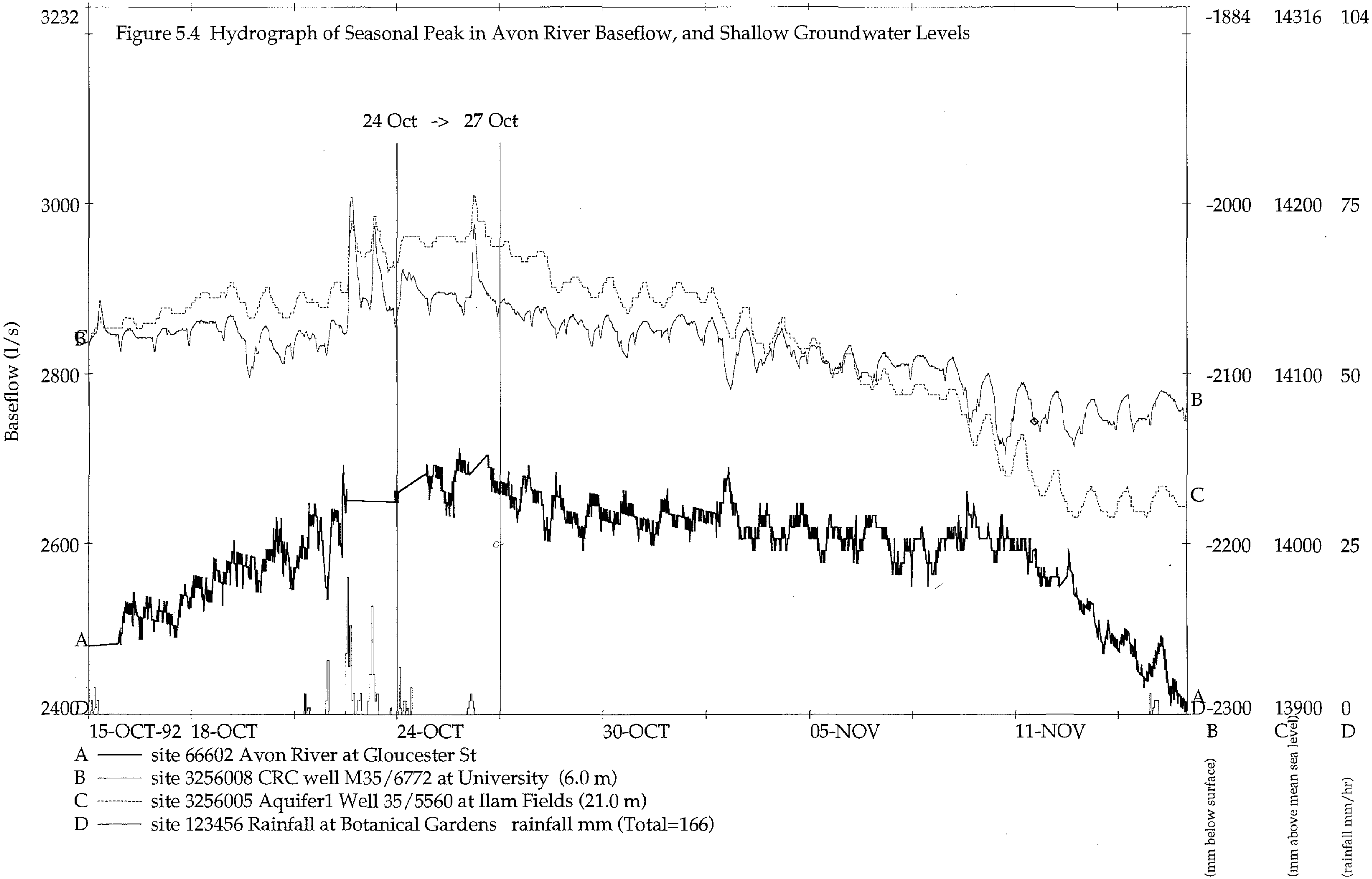


Figure 5.5 Regression Relationship Between Avon River Baseflow (at site 66602)and Groundwater Levels in Well M35/6772

$R^2 = 0.68$ with outliers; $R^2 = 0.92$ with outliers removed

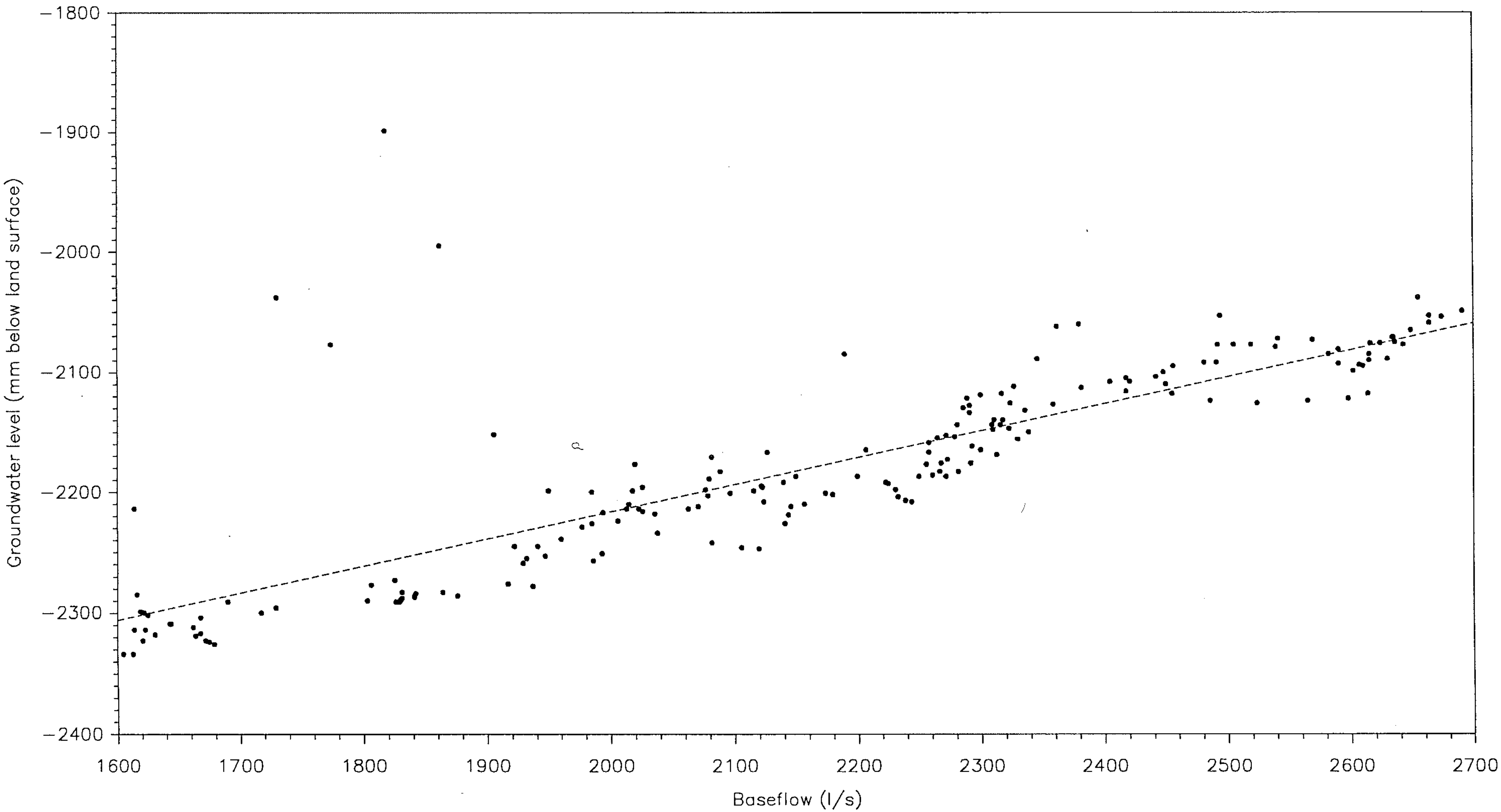
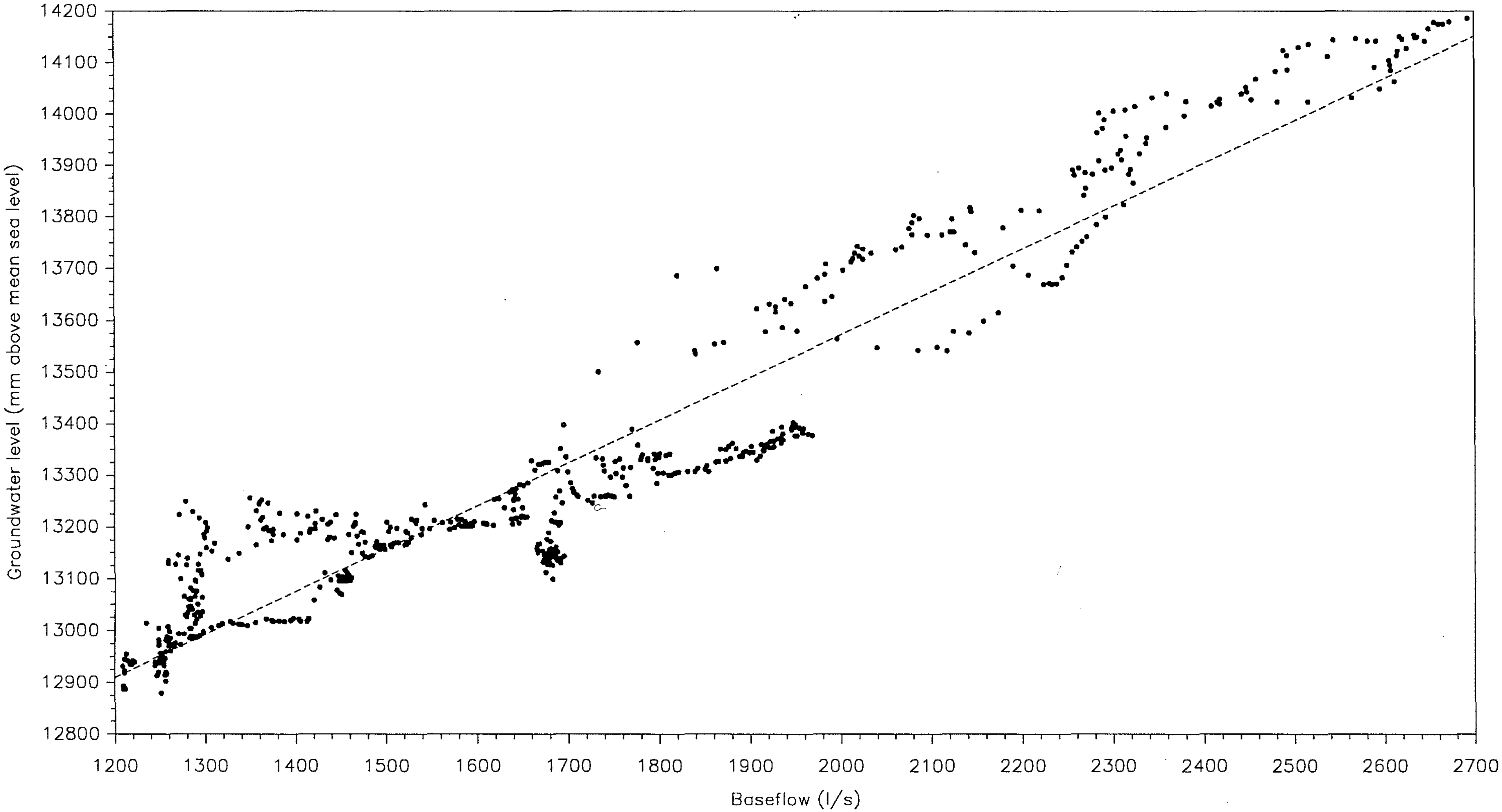


Figure 5.6 Regression Relationship Between Avon River Baseflow (at site 66602)and Groundwater Levels in Well M35/5560

$R^2 = 0.9065$



abstraction - stream discharge anti-correlation. The regression plots also indicate the relationship between Avon River baseflow and shallow groundwater levels. Correlation coefficients for the regression lines drawn between Avon River baseflow and groundwater levels measured in wells M35/6772 and M35/5560 are $R^2 = 0.68$ and 0.91, respectively. The lower R^2 value obtained between baseflow and well M35/6772 (Figure 5.5) is caused by the presence of outliers. The outliers represent the quick and relatively large rise in the groundwater level that occurs in well M35/6772 that is considered to be caused by air entrapment (see Section 5.2). When the outliers are removed the R^2 value increases to 0.92, which is close to the R^2 value obtained for the regression of well M35/5560. The unexplained scatter on the regression plots (Figures 5.5 and 5.6) is considered to be caused predominantly by a combination of the following factors:

1. Artificial discharge into the Avon River modifying the baseflow record.
2. Abstraction of groundwater by the University of Canterbury causing drawdown that modifies the groundwater level records in wells M35/6772 and M35/5560.
3. The approximations of the baseflow separation method that was used on the Avon River flow record (Section 3.4.2).
4. The time it takes for water to flow from the area adjacent to wells M35/6772 and M35/5560 to the recorder at Gloucester Street (site 66602). However, daily mean values were used in the regression analysis is and it is unlikely that this factor contributes much to the scatter.

The implication of the above data is that if shallow groundwater levels in the Avon River catchment decline due to increased abstraction or to a decrease in the amount of recharge then, a corresponding reduction in Avon River baseflow will result. The regression plots in Figures 5.5 and 5.6 provide information on how Avon River baseflow changes in response to variations in hydraulic head of the shallow groundwater system. However, it should be noted that inferences made on the change in Avon River baseflow that occurs in response to variation in groundwater levels measured in wells M35/5560 and M356772 do not allow for the fact that fluctuation in groundwater levels are not uniform throughout the study area. The seasonal fluctuation in groundwater levels measured in shallow wells during this study indicate that watertable fluctuation is greater in the western area of the catchment than in the eastern area (Figure 5.7) (see Figure 5.2 for the location of these wells). This is consistent with the observations of NCCB (1986) that, the fluctuation in unconfined groundwater levels increase westward.

5.3.2 SHALLOW GROUNDWATER LEVELS AND BASEFLOW OF THE TRIBUTARIES TO THE AVON RIVER

The data collected by the author during this project indicate in sub-catchments of the Waimairi and Wairarapa Streams there was no delay between seasonal peak in shallow groundwater levels and baseflow (see Sections 5.3.2.1 and 5.3.2.2). However, data indicate that a delay occurred between the peaks in Avon River Tributary baseflow and shallow groundwater levels (see Section 5.3.2.3).

Monitoring of the shallow watertable wells during this study was at approximately weekly intervals. Therefore, the period when maximum groundwater levels occurred in these wells is contained within an approximately two week "window". The period 24 to 27 October, when peak groundwater levels occurred in wells M35/6772 and M35/5560 (Figure 5.4), also occurs within the two week window in which maximum groundwater levels are indicated to have occurred in the wells that were monitored weekly (Figure 5.7). This suggests that groundwater levels throughout the study area have a similar trend, and that if delays do occur between peak groundwater levels in wells at a distance from the stream channel and those more proximal to the stream channel, then the delays are less than two weeks. It would be expected that if lateral flow of the shallow groundwater discharges into the Avon River system then, shallow groundwater levels measured close to a stream channel would decrease earlier than groundwater levels measured in a well at a greater distance from the

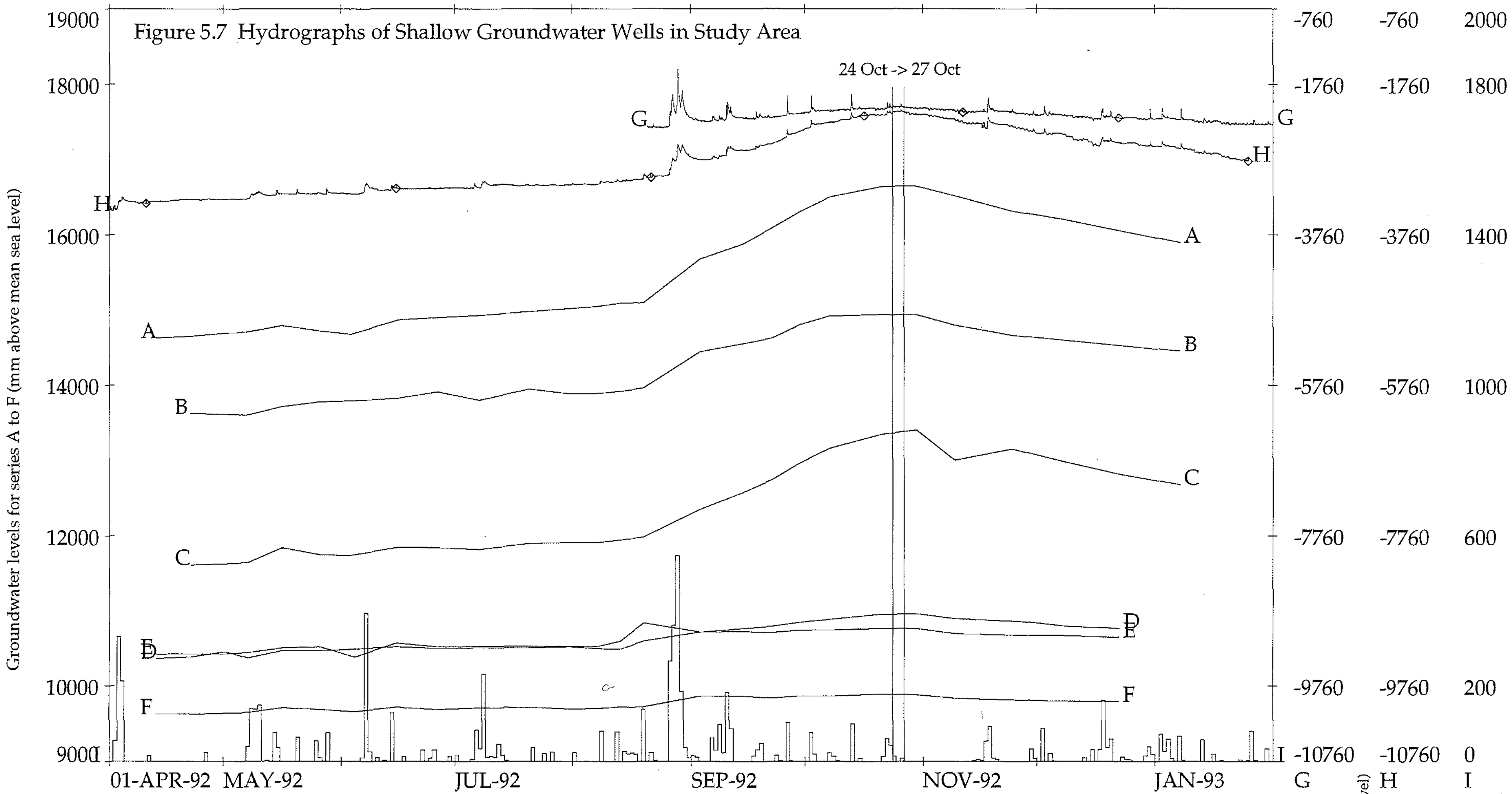


Figure 5.7 Hydrographs of Shallow Groundwater Wells in Study Area

A —— site 353169 Private well (15.0 m) at 20 Thurlestone Pl wtr level mm
B —— site 353775 Private well (19.3) at 276 Greers Rd wtr level mm
C —— site 355220 private well (5.0 m) at 15 Athol Tce wtr level mm
D —— site 354367 Private well (19.59 m) at 17 Ngahere St wtr level mm
E —— site 353785 Private well (7.7 m) at 8 Taylors Av wtr level mm
F —— site 353921 Private well (4.6 m) at 81 Glandovey Rd wtr level mm
G —— site 3256008 CRC well M35/6772 at University (6.0 m)
H —— site 3256005 Aquifer1 Well 35/5560 at Ilam Fields (21.0 m)
I —— site 123456 Rainfall at Botanical Gardens rainfall mm (Total=6889)

stream channel. The time difference between when groundwater levels start to decline in the two wells would be a function of the transmissivity of the aquifer material and the hydraulic gradient.

A delay might not occur between the peak in shallow groundwater levels measured in wells throughout the study area if a large component of the recharge to the shallow groundwater is by upward leakage from the deeper confined aquifer. In this case, shallow groundwater levels measured in a well would be a function of the hydraulic head of the underlying confined aquifer. The hydraulic head in the underlying confined aquifer is unlikely to be controlled by the location of the surface stream channels. This can not be verified by the approximately weekly groundwater level data collected during this study.

Baseflow - Groundwater Regression Analysis

Table 5.1 contains the residual errors (R^2) for baseflow - groundwater level regression analysis. For comparative purposes, baseflow data of all streams were regressed against the watertable levels measured in well M35/6772, which is a shallow watertable well that is centrally located in the study area and water levels were recorded at 15 minute intervals by an automatic recorder. In addition, each tributary flow record was compared to the closest monitored well. Although in some cases R^2 values decreased with increasing distance between the well and the stream channel, this trend is not definitive. By comparing the R^2 values of tributary baseflow against well M35/6772, the highest values were obtained for those tributaries that do not receive artificial discharge. The exception is Drain 23 which had a very minimal change in baseflow in relation to the seasonal fluctuation in groundwater levels at well M35/6772. The anomalous response of Drain 23's baseflow record is discussed in section 5.3.2.1.

Lowest R^2 values were obtained for those streams that receive artificial discharge (Table 5.1). In particular, very poor correlations were obtained for the Addington and Riccarton Drains (Table 5.1). This is because of the relatively large fluctuations

Table 5.1 Coefficients of Correlation (R) for Baseflow Vs Groundwater Level Regression

Data in brackets denotes the distance of the well to the closest point of the stream channel

	Artificial discharge	M35/6772 University (6.0 m)	M35/5560 Ilam Fields (21.0 m)	M35/5220 Athol Tce (5.0 m)	M35/3169 Thurlstone Pl (15.0 m)	M35/3775 Greers Rd (19.3 m)	M35/3785 Taylors Ave (7.7 m)	M35/3921 Glandovey Rd (4.6 m)	M35/5420 Kirkwood Intermediate (3.3 m)
Avon River @ Gloucester St (66602)	yes	0.68*	0.91*						
Addington Drain (66635)	yes	0.18 (2.6)							0.49 (0.7)
Riccarton Drain (66636)	yes	0.28 (1.0)							0.16 (0.2)
Avon River Trib. @ Harakeke St (66637)	yes	0.77 (0.05)		0.94 (0.05)					
Avon River Trib @ University (66638)	yes	**		0.82 (0.05)					
Okeover Strm (6660)	yes	0.82 (0.025)	0.77 (0.3)	0.91 (0.5)					
Waimairi Strm @ Daresbury Park (66641)	no	0.89 (0.3)		0.96 (0.8)	0.97 (0.5)				
Drain 23 (66642)	no	0.5 (0.5)	0.61					0.5 (0.7)	
Waimairi Stream @ Coldstream Crt (66644)	no	0.89 (0.8)			0.92 (0.5)				
South Branch @ Barlow Street (66643)	no	0.94 (0.8)		0.99 (0.8)	0.99 (1.0)				
Wairarapa Stream @ Garden Rd (66645)	yes	0.64 (1.0)			0.96 (0.05)	0.93 (0.5)	0.79 (0.05)	0.9 (0.1)	
Taylors Drain (66646)	no	0.8 (1.8)				0.96 (0.5)	0.9 (0.05)		
Wairarapa Stream @ Gleneagles St (66647)	yes	0.71 (1.3)			0.92 (0.3)				
Wai-iti Stream (66648)	no	0.81 (1.3)			0.87 (0.8)	0.91 (0.4)		0.83 (0.9)	

* data daily means from May 92-Dec 93

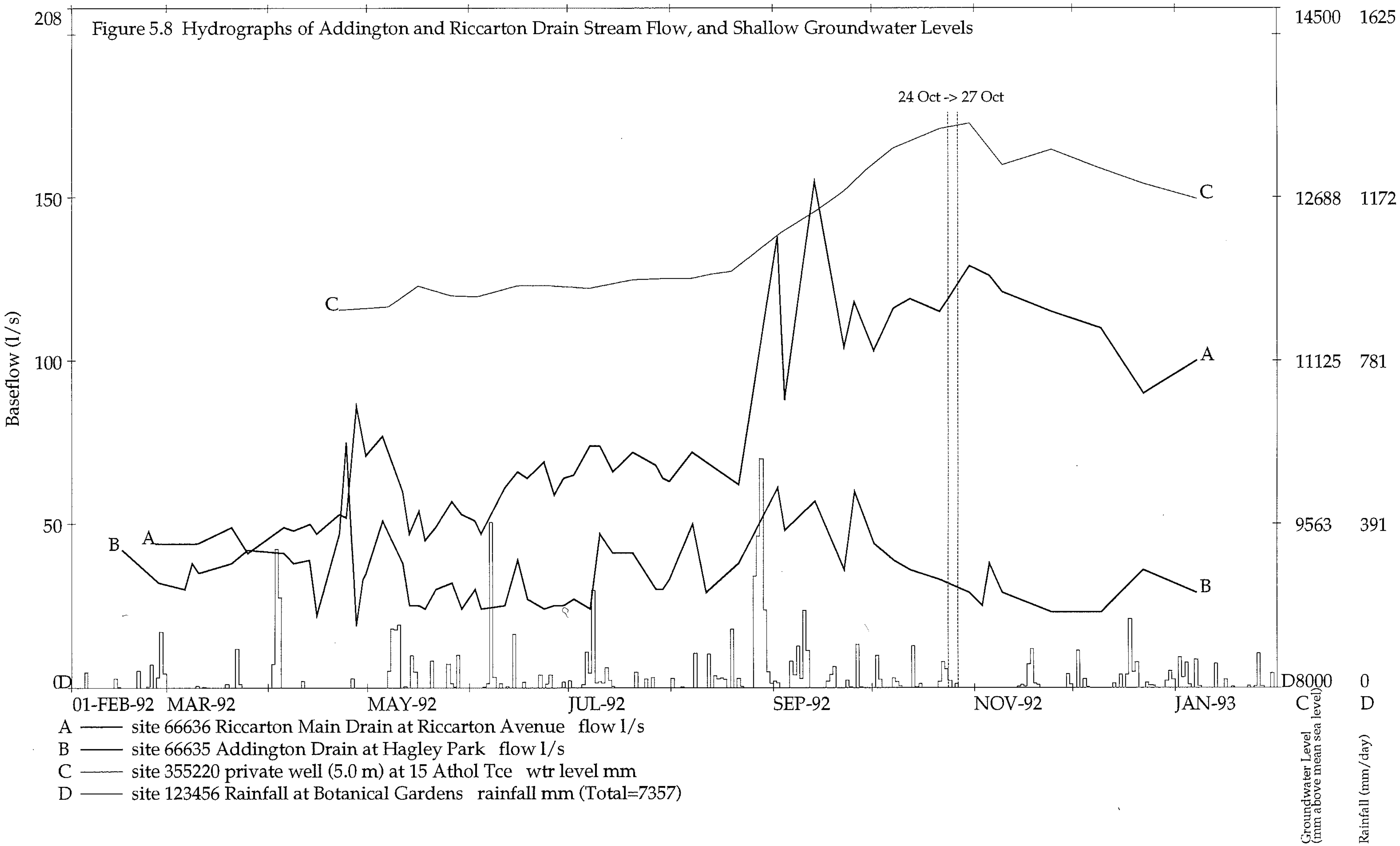
** insufficient data

in the flow record that were obtained for these drains (Figure 5.8). The Addington Drain receives discharge from Alpine Dairy Products. Although the discharge consent allows for 7.5 l/s (Appendix 2.1), the flow record suggests that this may have been exceeded on the odd occasion and at times water in the Addington Drain was white. Riccarton Drain also receives artificial discharge, but had a slightly better correlation with shallow groundwater levels. These two drains show a relatively poor groundwater - stream flow relationship, and provide minimal contribution to the Avon River systems baseflow (2 % and 5%). Because of this no discussion of the baseflow - groundwater level regression analysis of both these drains is included in this thesis.

It should be noted that the depth of the monitored wells varies (Table 5.1) and the shallow geology of the study area is variable. The implication of this is that groundwater levels measured in a well at distance from a particular tributary, which has a good correlation to that tributary's baseflow, may not measure groundwater levels in a similar stratigraphic sequence to that which occurs beneath the tributary. For example, groundwater levels measured in the watertable well M35/3169, that is located in an area where groundwater enters the stream by seepage through stream bed gravels, shows a good correlation ($R^2 = 0.92$) with Waimairi Stream baseflow measured at Coldstream Court (Site 66644). However, groundwater in this section of the Waimairi Stream catchment is considered to enter the stream predominantly through artesian springs that derive their water from gravels below a layer of confining sediments (Figure 5.2). The reason that a good correlation still occurs between the Waimairi Stream baseflow and well M35/3169 is that shallow groundwater levels measured in all the wells throughout the study area have very similar seasonal fluctuation patterns (Figure 5.7).

Further discussion on the results of the regression analysis obtained for each of the three main first order tributaries in the study area (Waimairi Stream, Wairarapa Stream and Avon River Tributary) is presented in the following three sections.

Figure 5.8 Hydrographs of Addington and Riccarton Drain Stream Flow, and Shallow Groundwater Levels



5.3.2.1 SHALLOW GROUNDWATER LEVELS AND WAIMAIRI STREAM BASEFLOW.

The Waimairi Stream receives no artificial discharge and all non-flood flow in the stream can be regarded as groundwater derived. Unfortunately, no shallow watertable wells occur within the area drained by the Waimairi Stream and its tributaries, the South Branch Stream and Drain 23. The closest monitored wells are M35/3169 and M35/5220 (Figure 5.2). In spite of the absence of proximal shallow wells, the baseflow hydrographs of the Waimairi Stream and its main tributary, the South Branch Stream, show a very similar trend to groundwater levels recorded in the two above mentioned wells (Figure 5.9). Figure 5.9 shows the baseflow record of the Waimairi Stream at both Daresbury Park (site 66641) and Coldstream Court (site 66644), and of the South Branch Stream (site 66643) and Drain 23 (site 66642).

The data indicate that no delay occurs between the seasonal peak in Waimairi Stream baseflow and shallow groundwater levels (Figure 5.9). However, as mentioned above, streamflow and groundwater level data were recorded at approximately weekly intervals, so the period when peak groundwater and streamflow levels occurred can only be determined to within an approximately two week "window".

Regression of the Waimairi Stream baseflow record at site 66641 against shallow groundwater levels in the closest monitored well (M35/3169) is shown in Figure 5.10. The R^2 value (0.97) indicates that there is an excellent correlation between baseflow periods in the Waimairi Stream and local shallow groundwater levels. This is expected as the Waimairi Stream receives no artificial discharge and non-flood stream flow is entirely supplied by groundwater. Even higher R^2 values (0.99) were obtained for the regression of South Branch Stream baseflow (a tributary of the Waimairi Stream) and shallow groundwater levels (Table 5.1).

<u>Waimairi Stream Baseflow and Artesian Spring Discharge</u>

Figure 5.11 shows the Waimairi Stream baseflow data recorded at site 66641, the groundwater level data recorded in well M35/3169 and the flow information on two

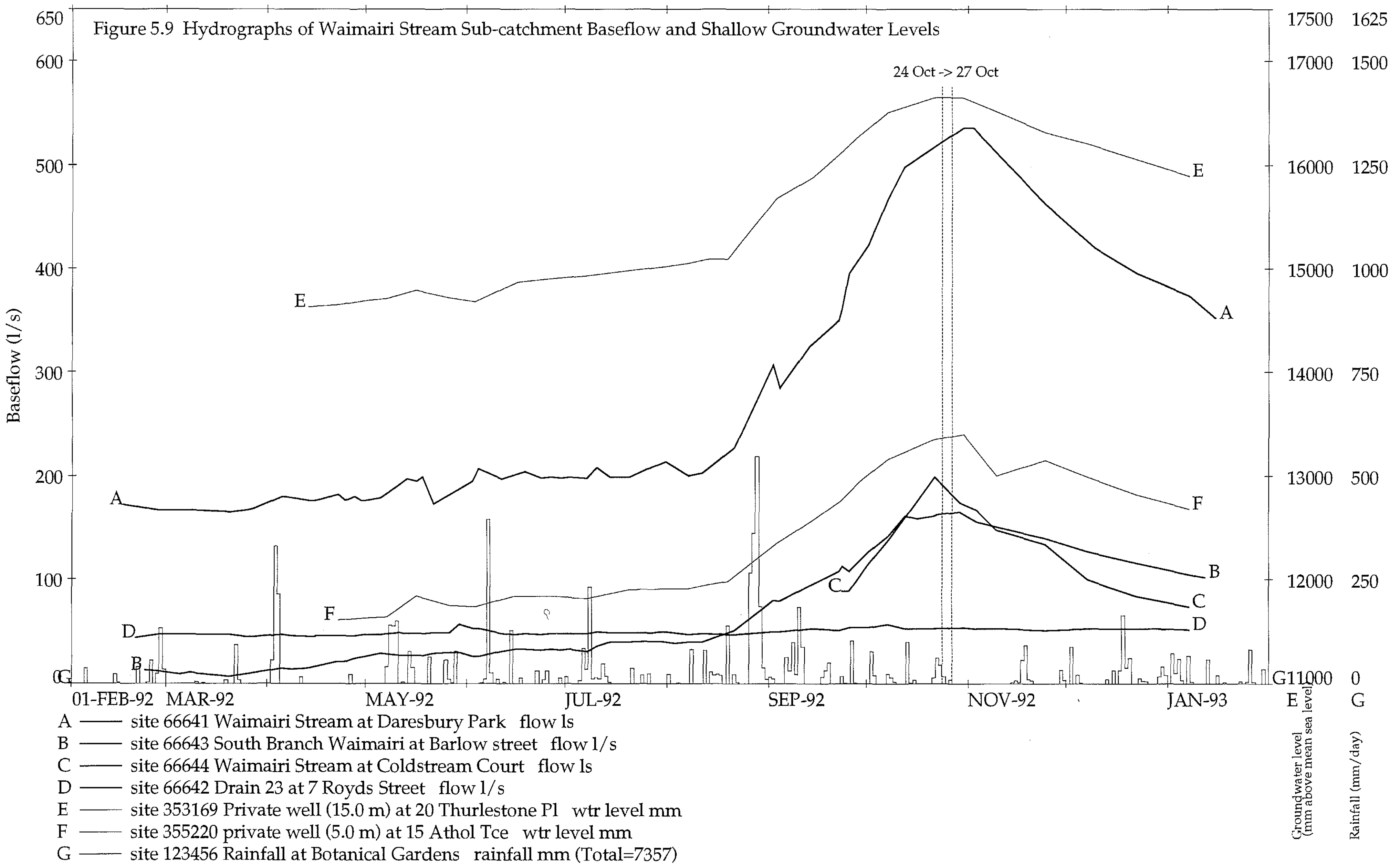


Figure 5.9 Hydrographs of Waimairi Stream Sub-catchment Baseflow and Shallow Groundwater Levels

Figure 5.10 Regression Relationship Between Wiamairi Stream Baseflow (at site 66641) and Groundwater Levels in Well M35/3169

$R^2 = 0.97$

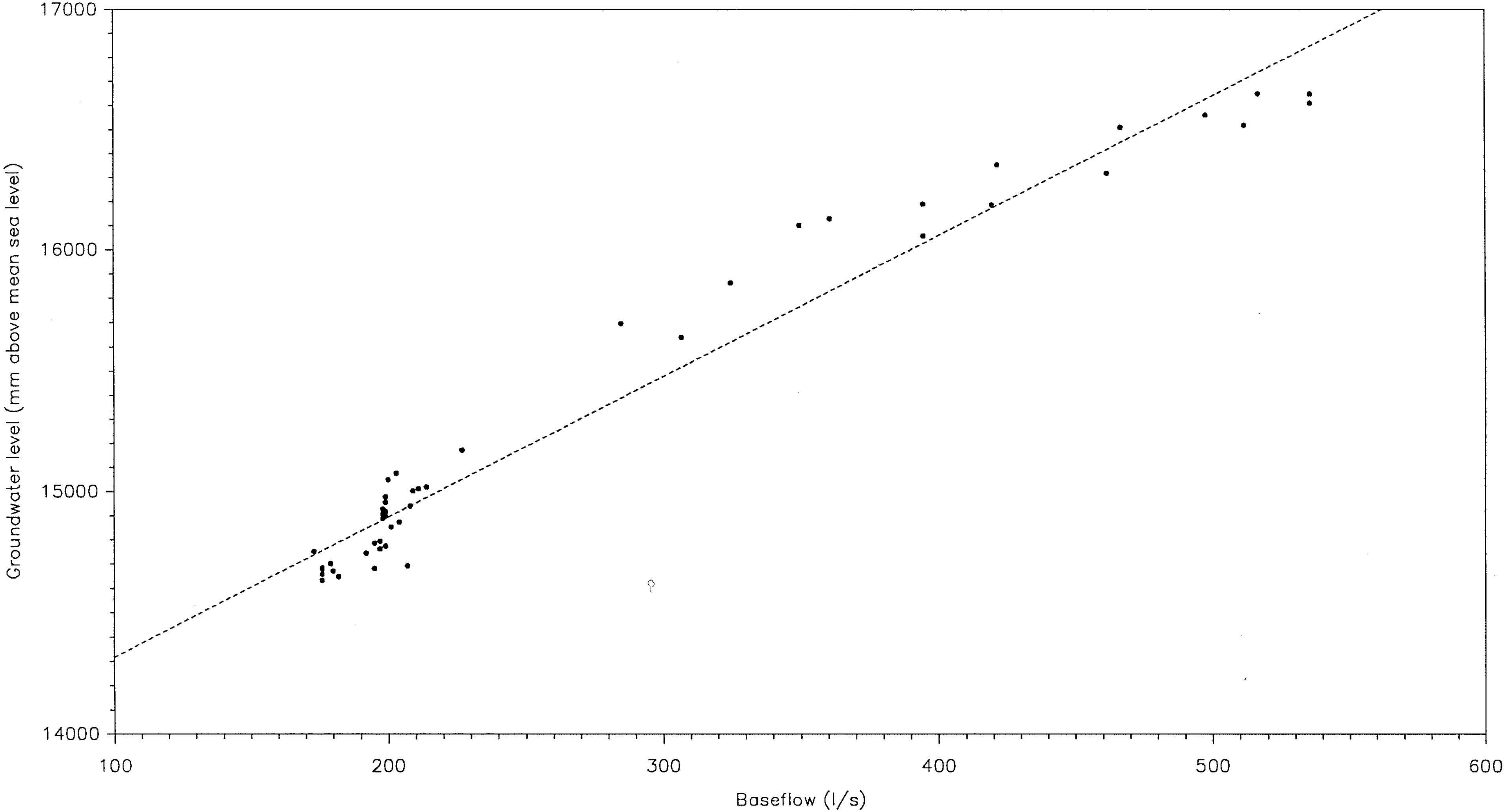
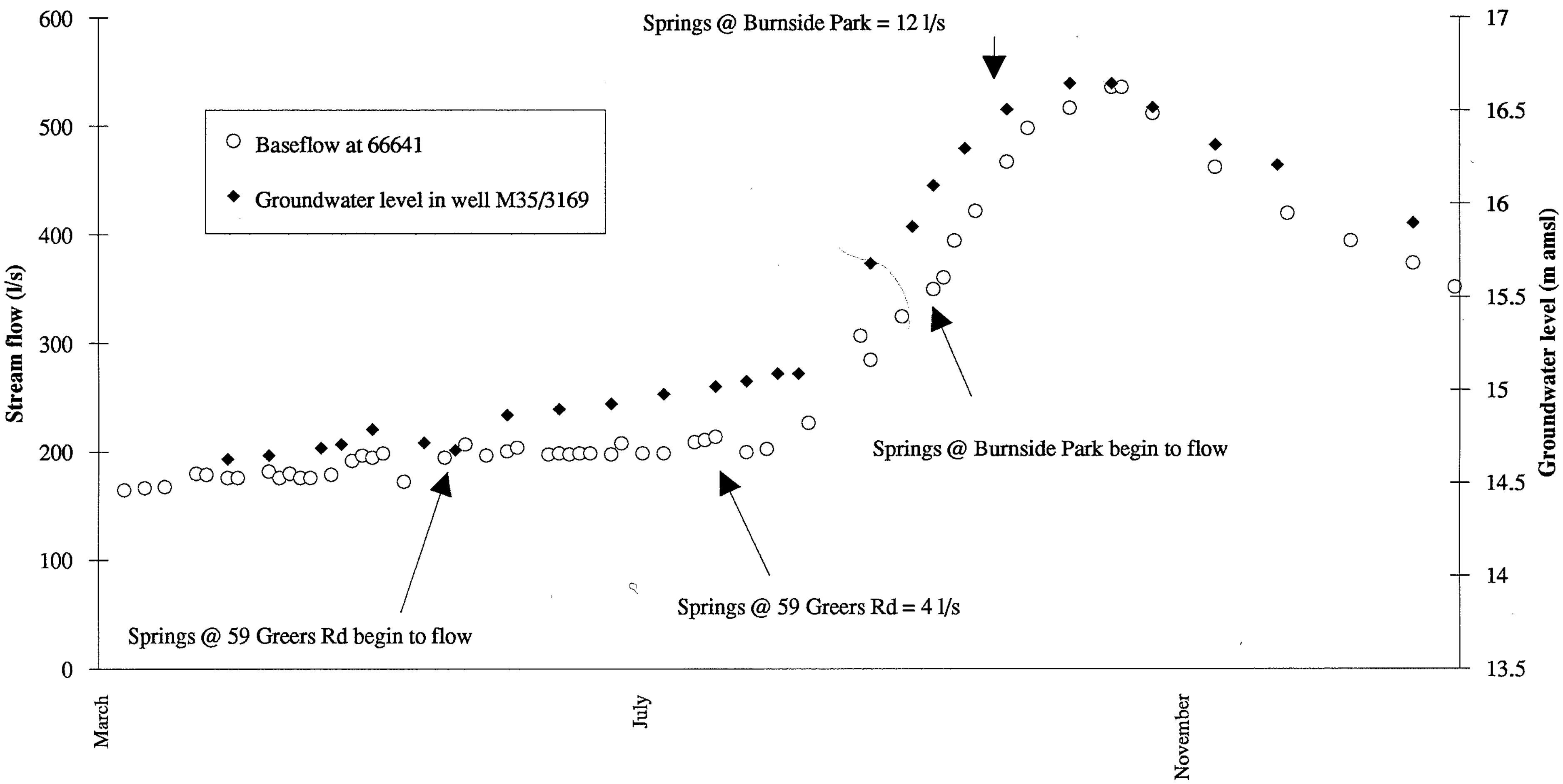


Figure 5.11 The Discharge of Two Artesian Spring Sections in the Waimairi Stream Relative to Baseflow Rates and Groundwater Levels

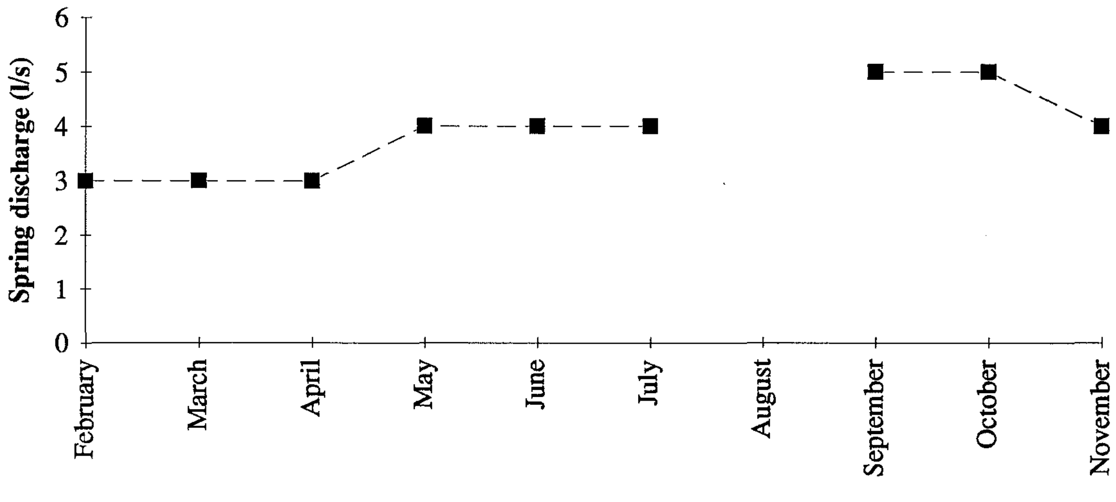


artesian spring areas that occur in the Waimairi Stream. The two spring sections are those immediately upstream of Greers Road and in Burnside Park (Figure 5.2). The spring flow data in Figure 5.11 indicate that the spring discharge at 59 Greers Road increased from 0 to 4 l/s between May and July in response to a 0.25 m increase in groundwater water levels in well M35/3169. Approximately two months later, springs at Burnside Park increased from 0 to 12 l/s between mid-September and early-October in response to a 0.4 m increase in groundwater level. Figure 5.11 supports the view that the discharge of artesian spring sections increases with rising groundwater level and the initiation of artesian spring flow with rising groundwater level is progressively westward. The seasonal increase in Waimairi Stream baseflow that occurred upstream of Greers Road is illustrated in Figure 3.5 (Chapter 3). The increase in baseflow upstream of Greers Road is largely attributed to these two artesian spring sections of the Waimairi Stream. The two spring areas showed a relatively significant increase in discharge in response to groundwater level rise when compared to artesian springs located further west in Drain 23. This difference in the amount that spring discharge varied seasonally in the study area is discussed below.

In comparison to the Waimairi Stream and South Branch Stream hydrographs, the hydrograph of Drain 23 had a very constant baseflow rate throughout the study period (Figure 5.9). The variation in Drain 23 mean monthly baseflow during the study was only 11 l/s (43 to 54 l/s), a 22% variation from mean annual flow. This is significantly lower than the percent variation that occurred in other streams in the catchment (refer Tables 3.1 and 3.2, Chapter 3).

In Drain 23, a relatively large artesian spring occurs on true river right at 7 Royds Street. The location of Royds Street is shown in Figure 5.2. This was the most easterly located spring monitored during the study. A number of gaugings were conducted upstream and downstream of the spring to ascertain the seasonal fluctuation in spring flow (Figure 5.12). It should be noted that the margins of error

Figure 5.12 Artesian Spring Discharge at 7 Royds Street, Fendalton



in the gaugings exceed the spring discharge, but the flow data indicates that there was a 2 l/s fluctuation in spring discharge during the study period. The discharge from this spring showed minimal seasonal variation relative to the more western located Waimairi Stream springs at Greers Road and Burnside Park (Figure 5.11).

The explanation for the relative small variation in Drain 23 baseflow and 7 Royds Street artesian spring discharge is that the range in fluctuation of the shallow groundwater levels decreases eastward as groundwater levels get closer to the surface. The hydrographs of the closest shallow groundwater wells that were monitored in the vicinity of 7 Royds Street (M35/3921, M35/5409, and M35/4367) all had a lower seasonal fluctuation than more western located wells. For example, eastern wells M35/3921 and M35/5409 had a seasonal fluctuation in measured groundwater levels of 0.27 m and 0.4 m, respectively; while well M35/3169, located in unconfined gravels in the western area of the study area, had a 2.02 m seasonal variation (Figure 5.7) This constitutes a 1.62 to 1.75 m difference in the seasonal fluctuation of groundwater levels measured in these wells.

The hydraulic head of the shallow groundwater aquifers is the "driving force" of the artesian spring discharge. As the head does not vary as much in the east of the study area as in the west, it follows that the seasonal variation in artesian spring discharge and in the component of baseflow that enters the river system in the east are also less variable.

5.3.2.2 SHALLOW GROUNDWATER LEVELS AND WAIRARAPA STREAM BASEFLOW

The baseflow hydrographs of the Wairarapa Stream and its tributaries, and of the shallow groundwater wells within the Wairarapa Stream drainage area, are shown in Figure 5.13. The data presented in Figure 5.13 indicate that, with the exception of Taylors Drain (site 66646), there was no delay between the peaks in Wairarapa Stream baseflow and shallow groundwater levels. Peak baseflow rates in Taylors Drain appear to have occurred approximately a month earlier within the period 22

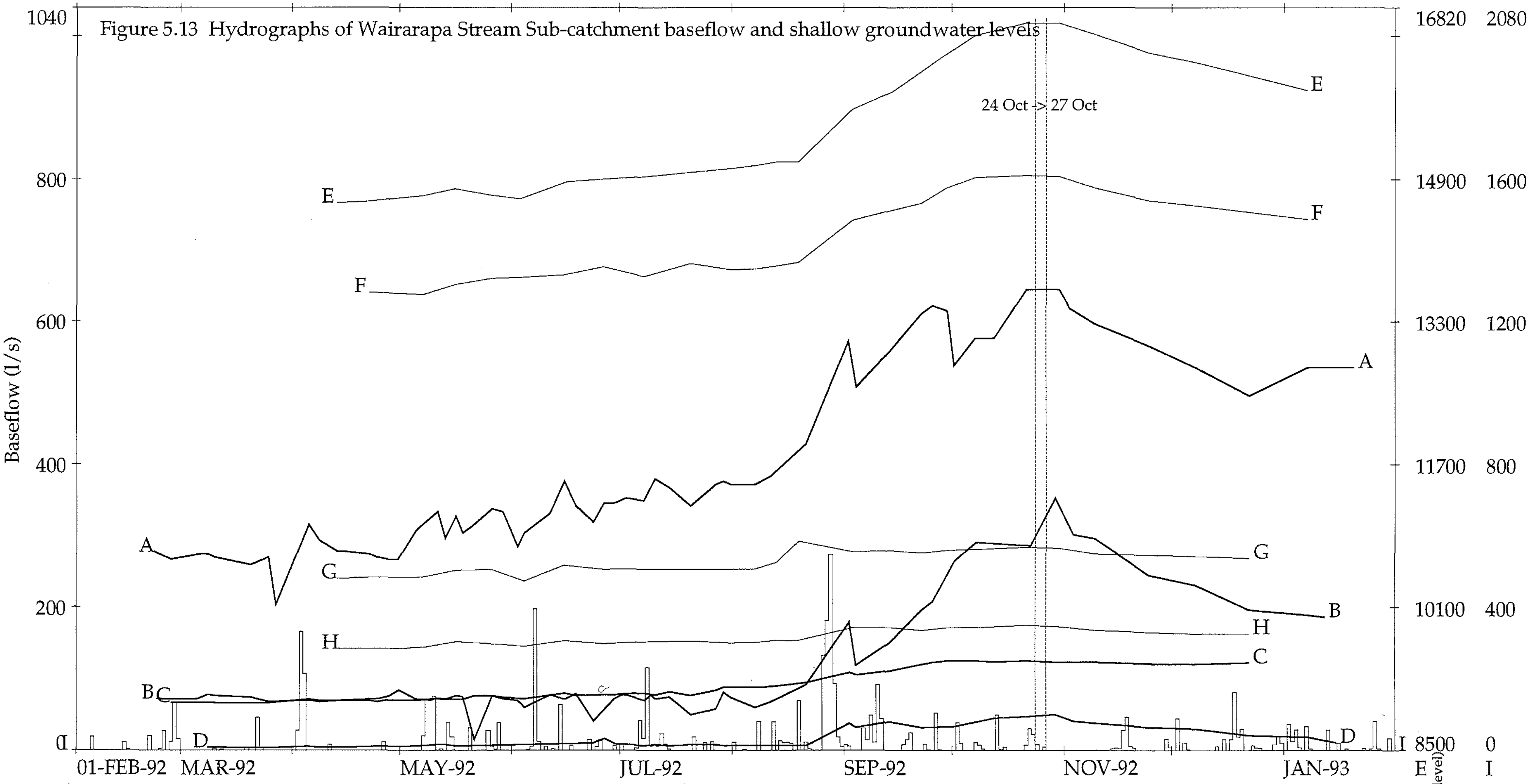


Figure 5.13 Hydrographs of Wairarapa Stream Sub-catchment baseflow and shallow groundwater levels

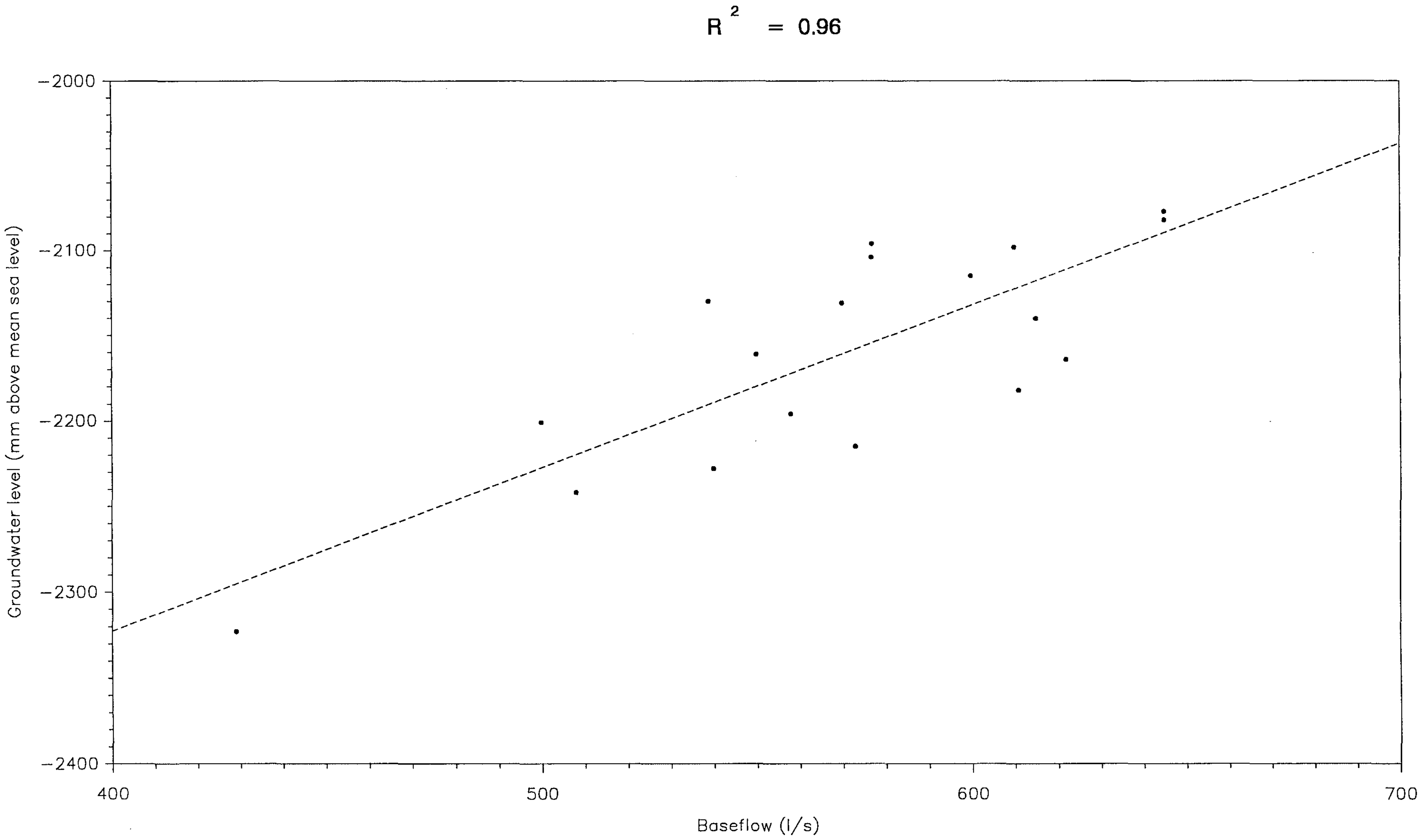
- A —— site 66645 Wiararapa Stream at Garden Road bridge flow l/s
- B —— site 66647 Wairarapa Stream at 42 Gleneagles Tce flow l/s
- C —— site 66646 Taylors Drain at Elmwood Park flow l/s
- D —— site 66648 Wai-iti Stream at Clyde Road flow l/s
- E —— site 353169 Private well (15.0 m) at 20 Thurlestone Pl wtr level mm
- F —— site 353775 Private well (19.3) at 276 Greers Rd wtr level mm
- G —— site 353785 Private well (7.7 m) at 8 Taylors Av wtr level mm
- H —— site 353921 Private well (4.6 m) at 81 Glandovey Rd wtr level mm
- I —— site 123456 Rainfall at Botanical Gardens rainfall mm (Total=7357)

September to 7 October (Appendix 3.13). However, the baseflow data of Taylors Drain that appear in Appendix 3.13 show that the difference in flow between the period 22 September to 7 October and the period 24 to 27 October, when peak baseflow rates occurred in the other tributaries is only 3 l/s. Weed removal in the vicinity of Taylors Drain gauging site that occurred at some time between 1 to 7 October caused a relatively large rating change (see Taylors Drain rating curve in Appendix 3.13). The next gauging of Taylors Drain after the weed removal was not conducted until 5 November. Because of this the Taylors Drain flow data between the date of weed removal and the gauging on 5 November is not considered reliable. Errors in the data over this period are thought to be less than several litres per second, and the peak in Taylors Drain baseflow may have occurred during the same period as the rest of the Wairarapa Stream.

Taylors Drain is the most easterly located tributary of the Wairarapa Stream sub catchment. The ratio of the range in Taylors Drain baseflow to maximum mean monthly baseflow during the study period was 45% (refer Table 3.2, Chapter 3). This is considerably less than the ratios obtained for the other second order tributaries and supports the observations in Section 5.3.2.1 that, the fluctuation in the groundwater supply to the Avon River system decreases eastward.

Figure 5.14 shows a regression plot of the Wairarapa Stream baseflow at Garden Road (site 66645) and shallow groundwater levels measured in well M35/3169. The R^2 value (0.96) indicates that there is a good relationship between Wairarapa Stream baseflow and shallow groundwater levels but there is greater scatter of the data than occurred with Waimairi Stream baseflow regression in Figure 5.10. The Wairarapa Stream baseflow at site 66645 has consistently lower R^2 values for the regression against shallow ground levels than the Waimairi Stream (Table 5.1). This is probably due to artificial discharge into the Wairarapa Stream at both Jellie Park and Clyde Road (Appendix 2.1) causing unnatural fluctuations in Wairarapa Stream baseflow record (Figure 5.13). Higher R^2 values were obtained for Taylors Drain, a tributary of Wairarapa Stream that receives no artificial discharge (Table 5.1).

Figure 5.16 Regression Relationship Between Wairarapa Stream Baseflow (at site 66645)and Groundwater Levels in Well M35/6772



5.3.3.3 AVON RIVER TRIBUTARY BASEFLOW AND SHALLOW GROUNDWATER LEVELS

Hydrographs of Avon River Tributary baseflow and shallow groundwater levels in the area drained by the Avon River Tributary are shown in Figure 5.15. Well locations and stream gauging sites are shown in Figure 5.1. Baseflow data collected at site 66638 after October 1992 are not included in the study because weed growth caused errors in the gauging data.

Data indicate that a delay occurred between the seasonal peak in shallow groundwater levels measured in wells M35/6772 and M35/5220, and the peak in Avon River Tributary baseflow (Figure 5.15). Groundwater levels recorded automatically at 15 minute intervals in well M35/6772 show that groundwater levels peaked in the area during the period 24 to 27 October (Figure 5.4) and the data from well M35/5220 is consistent with this (Figure 5.15). Streamflow measurements at site 66637 on the Avon River Tributary indicate that peak baseflow occurred some time during the period 30 October to 9 November (see Appendix 3.4). Stream flow measurements taken at site 66640 on the Okeover Stream indicate that the peak in baseflow occurred sometime between 29 October and 24 November (see Appendix 3.6). The more frequent measurements taken at site 66637 define the period in which peak baseflow occurred more accurately than at site 66640. However, the peak in Okeover Stream baseflow may have occurred at a different time than in the Avon River Tributary.

If the data from site 66637 are used to estimate the delay between peak groundwater levels and Avon River Tributary baseflow, then the delay period is between a minimum of 3 days (October 27 to October 30) and a maximum of 17 days (October 27 to November 9).

It should be noted that the Avon River Tributary receives artificial discharge from the University of Canterbury (see Appendix 3.1). The apparent delay between baseflow and groundwater levels simply be due to the University discharging more

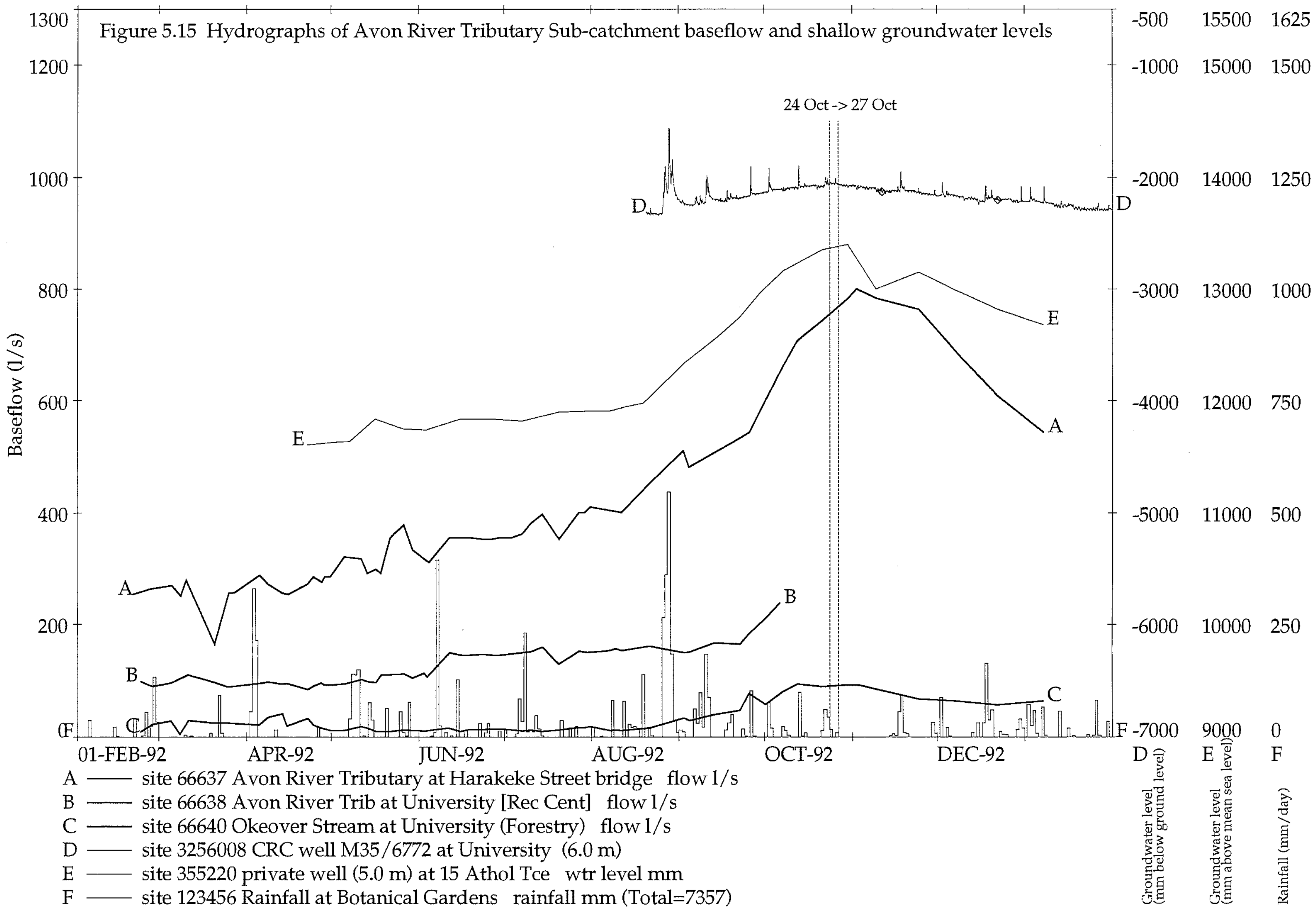


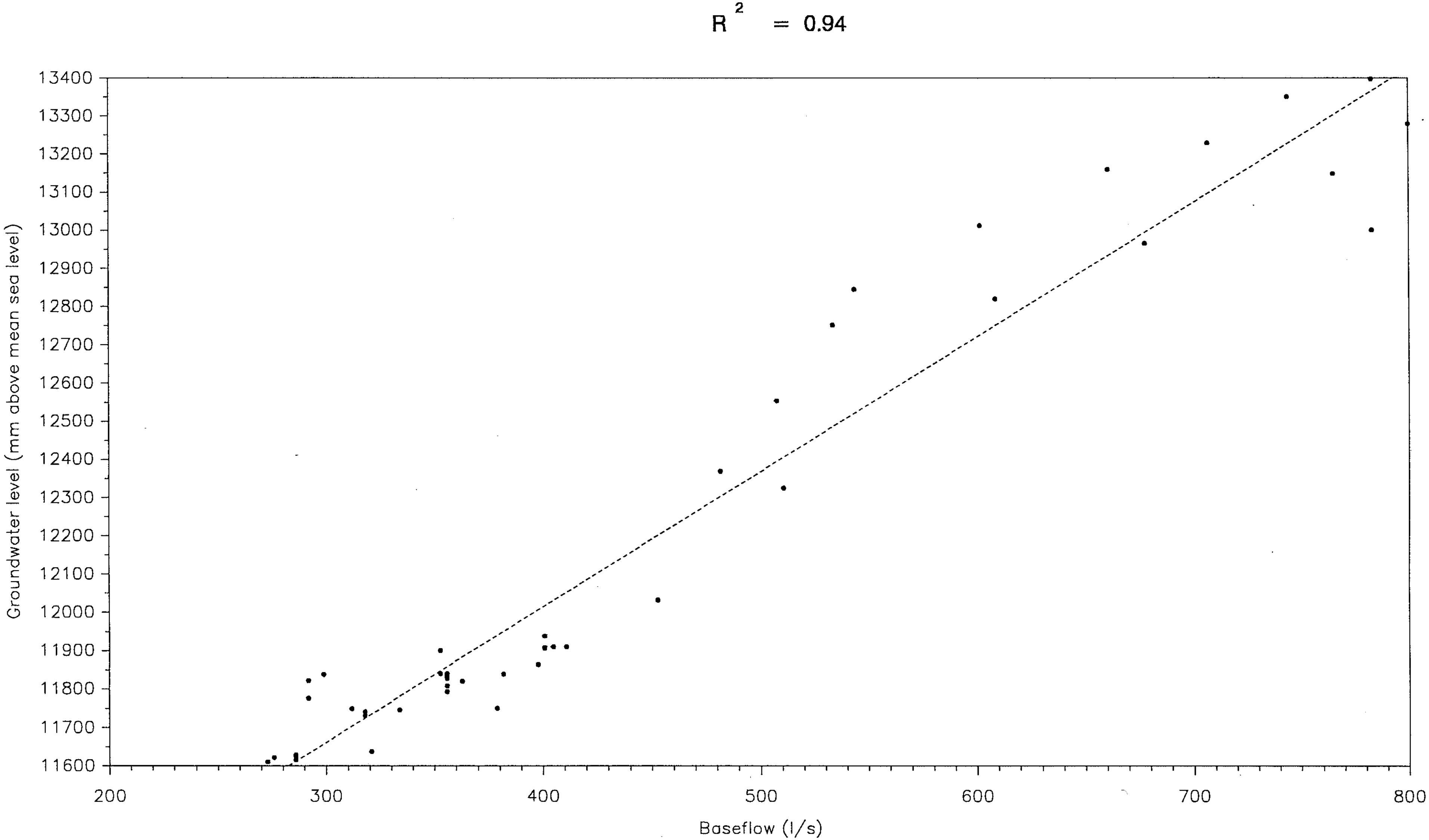
Figure 5.15 Hydrographs of Avon River Tributary Sub-catchment baseflow and shallow groundwater levels

water into the Okeover Stream and Avon River Tributary after the period 24 to 27 October than before the period. Unfortunately, details of University discharge were not recorded frequently enough during the time of stream flow measurements for this to be verified.

Another possible cause for the delay may be the hydrological parameters of the sediment underlying the Avon River Tributary. The transmissivity of the aquifer material that contains the groundwater which is the source of Avon River Tributary baseflow may be sufficiently low to cause a lower rate of groundwater through flow than occurs in the area of the catchment drained by the Waimairi and Wairarapa Streams where no delay was indicated by the data. The thickness of fine-grained surface sediment in much of the area drained by the Avon River Tributary is greater than in the areas drained by the Waimairi and Wairarapa Streams . Intuitively, the greater thickness of fine-grained sediment will cause the Avon River Tributary sub-catchment to have a lower average transmissivity value than one in which the surface sediment is dominated by gravel deposits. This is not able to be qualified due to the time restriction of this study, but is an aspect upon which future work on the Avon River baseflow may be concentrated.

Figure 5.16 shows a regression plot of the Avon River Tributary baseflow at Harakeke Street (site 66637) and shallow groundwater levels measured in well M35/5220. The R^2 value (0.94) indicates that there is a good relationship between Avon River Tributary baseflow and shallow groundwater levels but there is a greater scatter of the data than occurred with the regression of Waimairi and Wairarapa Stream baseflows against groundwater levels (Table 5.1). The lower R^2 value for the Avon River Tributary is probably due to 1) artificial discharge of cooling water into the Avon River Tributary and Okeover Stream at the University (Appendix 2.1) causing unnatural fluctuations in baseflow record, especially in the summer months, and/or 2) the apparent delay between the peak in shallow groundwater levels and Avon River Tributary baseflow. The R^2 values of the regression between Avon

Figure 5.16 Regression Relationship Between Avon Tributary Baseflow (at site 66637) and Groundwater Levels in Well M35/5220



River Tributary baseflow and groundwater levels in well M35/5220 increased to 0.96 and 0.95 when the groundwater level data was lagged by 1 week and 2 weeks, respectively. As noted above the delay between peak baseflow and groundwater levels is indicated to be between 3 and 17 days. The lagged R^2 values are very similar to those obtained from the Wairarapa Stream baseflow - groundwater regression where no delay between peaks in baseflow and groundwater level is indicated by the data.

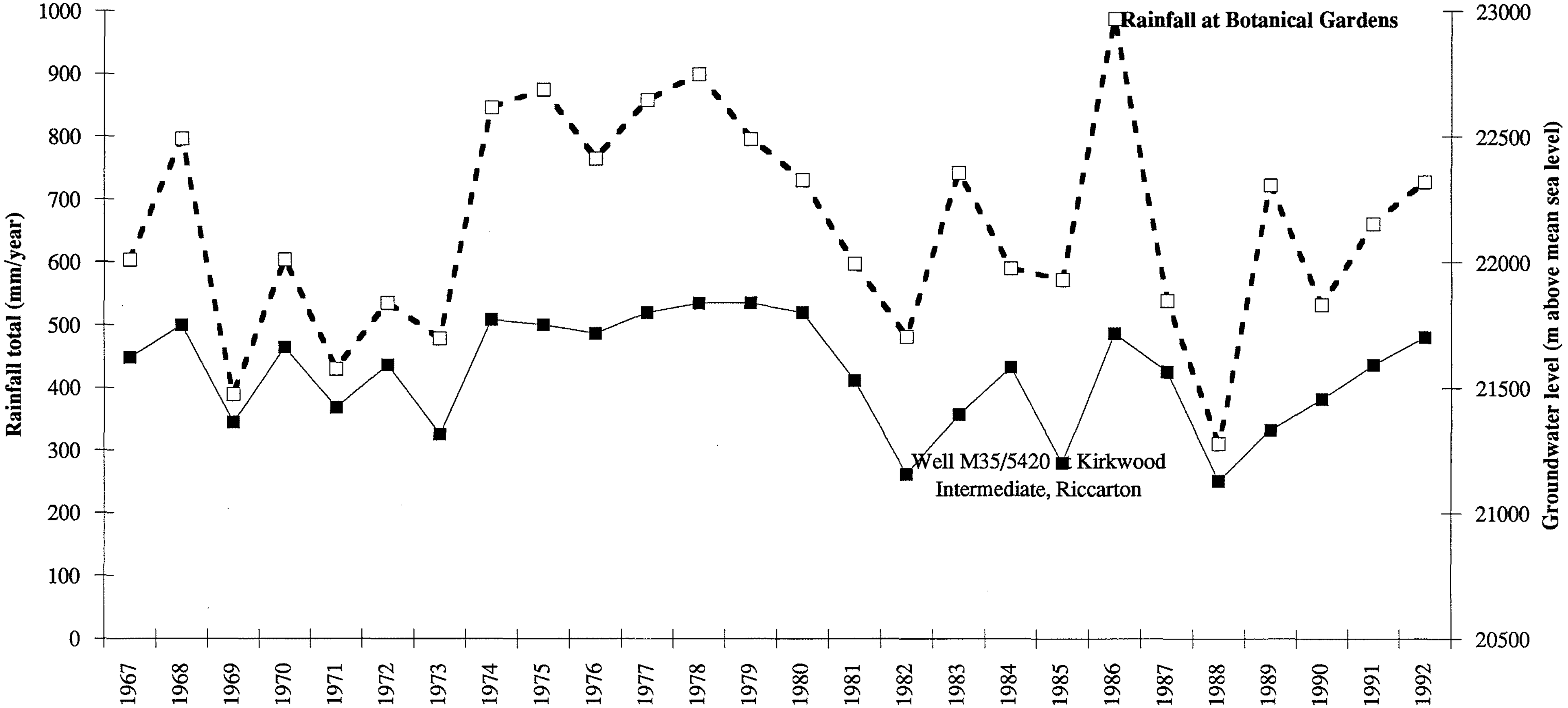
5.4 THE RELATIONSHIP BETWEEN SHALLOW GROUNDWATER LEVELS AND LOCAL RAINFALL (A BRIEF OVERVIEW)

5.4.1 SHALLOW GROUNDWATER LEVELS AND LOCAL RAINFALL

Figure 5.17 is a plot of yearly rainfall totals at Botanical Gardens and mean yearly groundwater levels at bore M35/5420. The use of yearly data eliminates similarities in seasonal variation between the two data series (i.e., the lowest groundwater levels and rainfall totals occurring in summer). The plot indicates that a similar pattern occurs between watertable levels and local rainfall totals. The years when highest and lowest rainfall totals occurred coincide with those years when the minimum and maximum average yearly groundwater level occurred. A similar trend may be expected to occur between local rainfall and Avon River baseflow. However, limited data restricted this analysis and no definitive trends could be obtained.

Anecdotal information suggests that a decline in artesian spring discharge is occurring where new housing developments are being established near areas where groundwater enters the Avon River System (see Section 3.2). The drainage of the land and construction of impervious surfaces that are associated with housing development may reduce shallow groundwater levels and the amount of rainfall that is available to recharge the watertable by infiltration.

Figure 5.17 Yearly Christchurch Rainfall Totals at Botanical Gardens and Average Yearly Watertable Level in Well M35/5420



While Waimakariri-derived shallow groundwater is indicated by isotope data to be the source of the majority of the shallow groundwater that supplies the Avon River baseflow, the infiltration of local rainfall appears to act as a "top up" to the shallow groundwater supply (Figure 5.17). Reducing rainfall infiltration by the construction of impervious surfaces and the rapid removal of storm water from the catchment by a hydraulically efficient artificial drainage networks may be a factor in the historical decline of Avon River baseflow.

5.4.2 RAINFALL TRENDS IN CHRISTCHURCH AND THE SURROUNDING AREA

Cycles and trends in Christchurch and Canterbury rainfall data have been identified by several authors (eg Vines and Tomlinson 1980; Cherry and Larson 1990). Since the infiltration of local rainfall appears to recharge the shallow groundwater beneath Christchurch (Figure 5.17), then cycles and long term trends in local rainfall will have an effect on the shallow groundwater levels. Natural fluctuations in Avon River baseflow could then be expected to occur in response to rainfall cycles. The present Avon River data is insufficient to determine if yearly variations in baseflow reflect rainfall cycles.

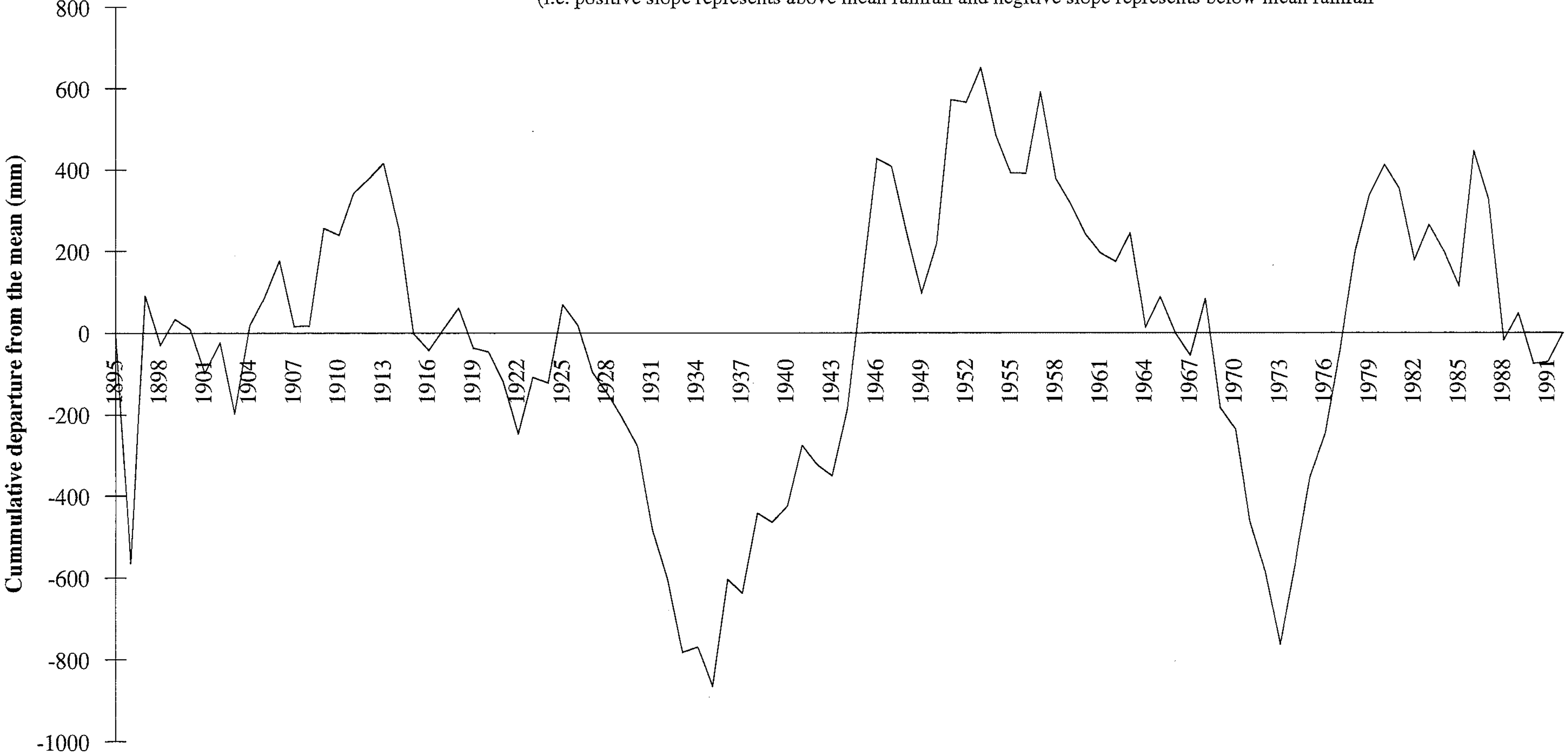
Cherry and Larson (1990) used linear regression to identify longer term trends in Canterbury rainfall. They concluded that in the Canterbury region, with the exception of the inland southern Plains and alpine areas, there has been a declining trend in the rainfall, which is especially marked since the 1940's. The decline was found to be consistent with the regional circulation pattern changes.

Botanical Gardens rainfall data were analysed during this study to determine the trend in rainfall within the Avon River catchment (Figure 5.18), whch shows a long term trend that is consistent with the results that Vine and Tomlinson (1980) and Cherry and Larson (1992) obtained for the Canterbury Region. From approximately mid-1940's to 1992 there has been an overall declining trend in local rainfall . The increase in rainfall

Figure 5.18 Cummulative Departure from the Mean of Yearly Rainfall Totals at Botanical Gardens, Christchurch (1895-1992)

* slope at any point on the curve represents the ratio of the current yearly rainfall total to the mean

(i.e. positive slope represents above mean rainfall and negitive slope represents below mean rainfall



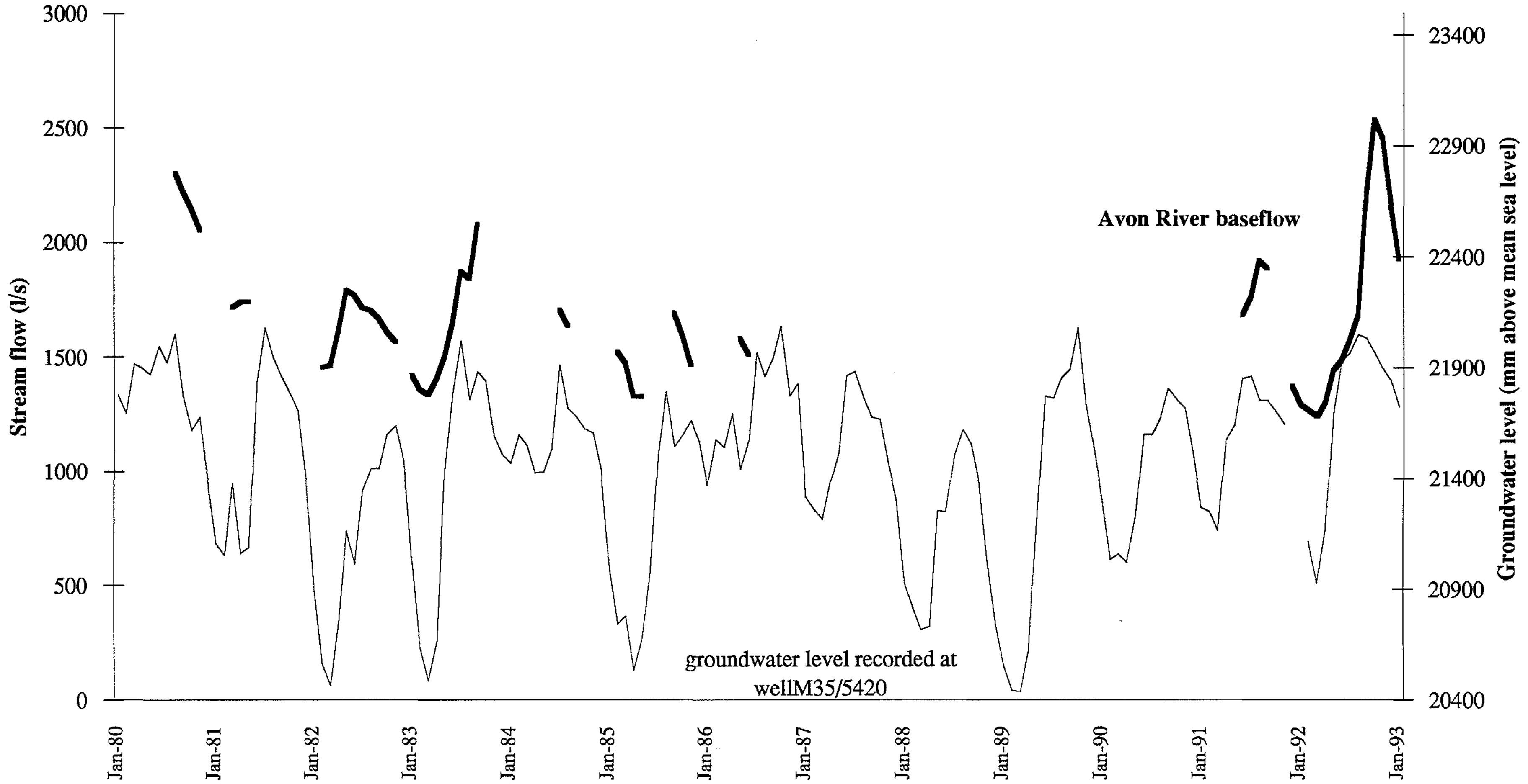
totals that occurred in the mid to late 1970's coincides with the relatively high annual average watertable levels recorded in well M35/5420 (Figure 5.17). The declining trend in the Christchurch area rainfall since the 1940's may have also contributed to the historical decline in Avon River baseflow.

5.4.3 SHALLOW GROUNDWATER LEVEL TREND

Figure 2.8 (Chapter 2) is a hydrograph of the longest shallow groundwater level record in the study area. The 30 m deep bore is located at the museum and taps the first confined aquifer. The record shows that the average level declined by about 0.5 - 1.0 m over the period 1895 - 1905, and then remained steady (but fluctuated seasonally) through to 1992. NCCB (1986) noted that the abstraction of water from the aquifers beneath Christchurch was occurring at an increasing rate, but the fears of over exploitation could not be substantiated because groundwater levels had not continued to decline and had even returned to near the original levels during the wet years of the mid 1970's. McCammon (1976) analysed fluctuations in this and another historical well and considered the records were conclusive evidence that there was no decline in the long term level.

The longest watertable well record in the study area (1967 to 1993) is from well M35/5420, a 3.3 m deep well at Kirkwood Intermediate, Riccarton (Figure 3.9; see Figure 5.2 for well location). The fluctuating line is the weekly data record, while the smoother line is a moving average using a 25 month window. The moving average indicates that no declining trend has occurred over the length of the record, but a general lowering in groundwater levels is indicated to have occurred from 1980 to approximately 1988. From approximately 1989 to present an increase in groundwater levels is indicated. Figure 5.19 shows the mean monthly Avon River baseflow data and groundwater levels measured in the same well (M35/5420). Although limited, the Avon River baseflow data does show a similar trend to the groundwater levels in this well.

Figure 5.19 Mean Monthly Avon River Baseflow and Groundwater Levels in Well M35/5420



It is apparent from historical and anecdotal information presented in this thesis that Avon River baseflow has declined over European settlement of the Christchurch area. However, shallow groundwater level data although fluctuating, does not indicate that a decline in shallow groundwater levels has occurred (Figure 3.9). Unfortunately no long term shallow groundwater data exist in the area of the catchment where groundwater is known to supply Avon River baseflow, and it is not known if the groundwater data presented in Figures 3.9 and 2.6 are indicative of long term groundwater levels throughout the catchment.

CHAPTER 6 SUMMARY AND CONCLUSIONS

6.1. AVON RIVER BASEFLOW INVESTIGATION

Baseflow was separated from the Avon River flow record by drawing a straight line from the start of the flood hydrograph rise to the baseflow separation point on the recession limb. The recession point was determined by the intersection of two straight recession lines on plots of logarithmic flow versus time. Baseflow analysis carried out during this study found that mean Avon River baseflow at Gloucester Street for the periods of reliable record from 1980 to 1992 is approximately 1700 l/s. The 11 month record (February 1992 to January 1993) of baseflow in the monitored tributaries of Avon River system indicates that on average 84% of the baseflow at Gloucester Street is supplied by the five first order tributaries. The remaining 16% is attributed to groundwater entering the Avon River between approximately Mona Vale and Gloucester Street.

Anecdotal and historical information indicate that a decline in Avon River baseflow and spring discharge has occurred since European settlement of the Christchurch area in the 1850's. However, insufficient long term flow data makes impossible a reliable quantitative analysis of the trend in Avon River baseflow. The "tentative results" obtained from the analysis of available flow data are that the lowest baseflow rates consistently occur between the months December to May. Flow rates of all the first order tributaries in 1992 were on average approximately 43% of their 1980 flow rates. This was supported by recorded flow data at Gloucester Street, which showed a 50% reduction in mean monthly baseflow data between March 1980 and March 1992. Large rainfall events in August-September 1992 caused the average baseflow rates of the tributaries in January 1993 to return to 82% of their March 1980 value. This is supported by the Avon River baseflow record at Gloucester Street which showed January 1992 to be 77% of the March 1980 value.

6.2 HYDROGEOLOGY OF THE AVON RIVER SPRINGS

The models presented in this thesis propose that groundwater enters the stream by two mechanisms - artesian spring discharge and groundwater seepage through stream bed gravels.

Avon River water that is supplied by groundwater seepage through stream bed gravels is thought to be derived directly from the watertable aquifer. Groundwater seepage through stream bed gravels occurs where the stream channel intersects near-surface gravel deposits and the watertable aquifer.

Artesian spring water is considered to flow directly from both the watertable aquifer and from Aquifer 1 in those localities where stream channels are situated above water-bearing gravels that are confined by between approximately 1 to 10 m of fine-grained sediment. "Pipes" through the fine grained sediment connect the spring vents to the underlying gravel aquifer, and where the hydraulic head of the underlying gravel aquifer is above the stage height of the stream, artesian spring flow will occur.

In stream sections where no artesian springs or groundwater seepage through stream bed gravels were observed, flow data indicate that stream flow continues to increase downstream. For example, the Avon River Tributary at Harakeke Street (site 66637) received on average 41% of its baseflow over the lower half of its reach. This stream section contained no observable artesian springs or localities of groundwater seepage through stream bed gravel. The increase in stream flow is attributed to the drainage of the watertable aquifer into the stream channel where the level of the watertable aquifer is higher than the stage of the stream.

6.3 RELATIONSHIP BETWEEN BASEFLOW AND SHALLOW GROUNDWATER LEVELS

Regression analysis indicates that there is a very good correlation between Avon River baseflow and shallow groundwater levels. R^2 values of 0.91 and 0.92 were obtained for the regression of Avon River baseflow at Gloucester Street against groundwater levels measured in Aquifer 1 well M35/5560 and in the watertable well M35/6772, respectively. The unexplained residual error in the data is considered to be caused by a combination of artificial discharge into the Avon River modifying the flow record, abstraction of groundwater modifying the groundwater record, and the approximation of the baseflow separation method.

Good regression relationships ($R^2 > 0.8$) were also found between shallow groundwater levels and the baseflow in the tributaries that do not receive artificial discharge. The highest R^2 value (0.99) was obtained for the South Branch (Waimairi) Stream, whilst the poorest groundwater - baseflow relationship ($R^2 < 0.4$) was obtained for Addington and Riccarton Drains which had a significant proportion of their non-flood flow supplied by artificial discharge.

Watertable well M35/6672 and Aquifer 1 well M35/5560 (both fitted with automatic recorders) showed that the seasonal maximum in groundwater level occurred over the 3 day period from October 24 to October 27. Data indicate that the peak in shallow groundwater levels throughout the study area was also at this time. No time delay was indicated to occur between the seasonal peak in shallow groundwater levels and Avon River baseflow at Gloucester Street. This is consistent with the baseflow - groundwater level data collected in the Waimairi and Wairarapa Stream sub-catchments. However, a delay of between 3 and 17 days may have occurred between peak groundwater levels and baseflow in the Avon River Tributary sub-catchment. This delay is considered to be caused by either artificial discharge from the University modifying the baseflow record, or by the thickness of fine grained surface sediment in the Avon River Tributary catchment causing a low rate of groundwater through flow. This cannot be verified from available data.

Flow data indicate that the seasonal variation in spring flow is greater in the western area of the study area than in the eastern area. In addition, the seasonal fluctuation in baseflow of Drain 23 (site 66642), the most easterly located tributary in the study area that did not receive artificial discharge, was 22% of its mean baseflow. The next lowest percentage variation from mean baseflow for a more westerly located tributary was 55% for the Wairarapa Stream (site 66645). The westward increase in the seasonal fluctuation of spring discharge and tributary baseflow corresponds with a westward increase in the seasonal fluctuation of shallow groundwater levels. Groundwater data showed that the seasonal fluctuation of groundwater levels in the western area of the study area is approximately 1.7 m greater than in the eastern area.

The summer Avon River flow record at Gloucester Street indicates that the nightly abstraction of shallow groundwater for irrigation at the University of Canterbury causes a reduction in Avon River flow. In the weekends when no daytime abstraction of shallow groundwater occurs at the University, peak flow rates occur at night in response to fluctuations in shallow groundwater levels.

6.4 CHANGES IN THE AVON RIVER LOW FLOW REGIME

In historical times there has been a change in the low flow hydrology of the Avon River system. Prior to European settlement of the Christchurch area the baseflow of the Avon River was supplied by drainage of wetland areas and by the discharge of shallow groundwater via spring flow. The catchment was characterised by a significantly higher watertable, in places in excess of 3 m above its present elevation. The progressive development of Christchurch has caused a reduction in wetland area, and today the baseflow of the Avon River is derived almost entirely from spring flow.

Because Avon River baseflow is a function of shallow groundwater levels, a decline in shallow groundwater levels in areas of the catchment where groundwater is known to enter the stream will cause a reduction in baseflow. Anecdotal information from river-side residents suggests that a decline in spring discharge has occurred following housing developments in the vicinity of spring localities. The construction of impervious surfaces, and a more efficient artificial drainage system that have resulted from housing development almost certainly lead to less recharge to the watertable aquifer from the infiltration of local rainfall.

Although the quantity of groundwater abstracted from beneath Christchurch has progressively increased since European settlement, historical groundwater data indicate that the shallow groundwater levels have not declined since 1905. However, high rates of groundwater abstraction are considered to accentuate the natural seasonal fluctuation patterns in groundwater levels. This may cause low Avon River baseflow rates to occur when periods of low shallow groundwater levels result from below average local rainfall.

The Canterbury Regional Council is developing a management plan to maintain acceptable levels of Avon River baseflow. The management plan includes such measures as restricting groundwater abstraction in spring areas. The results of this study confirm the need to maintain adequate shallow groundwater levels in areas where groundwater contributes to Avon River baseflow. To ascertain the effectiveness of remedial measures the monitoring of the Avon River low flow regime needs to be continued. This study has provided a data base which future studies can use to ascertain changes in Avon River baseflow.

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Appendix 2.1 Discharge Consents in the Avon River

	l/s	cubic meters/day		Discharge Occurence
Addington Drain	7.5	646	Alpine Dairy Products	?
Riccarton Drain	8	691	MAF Fisheries	?
Avon River Trib.	33 50	2849 1440	University - cooling water University - pump tests	weekdays during summer very infrequent
Okeover Stream	84 2592	7298 81000	University - cooling water University - Fluid Mech. Lab.	weekdays during summer very infrequent
Wairarapa Stream	75	450	CCC - well development at Clyde Road	April 1992 - ?
Hewlings Stream	50	4320	CCC - Jellicoe Park	almost constant

APPENDIX 2.2 Meteorological Data at Three Christchurch Sites (Meteorological Services Miscellaneous Publication 177)

H32451 CHRISTCHURCH AIRPORT — GRID REFS. NZMS 1. 1.63360 S076918611; NZMS 260. 1:50000 M35726461 — LAT. 43 29S LONG. 172 32E HT. 30 M.

	PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
RAINFALL. MILLIMETRES														
HIGHEST MONTHLY/ANNUAL TOTAL	1943-1980	139	144	173	199	198	168	181	149	120	137	140	149	987
90 PERCENTILE VALUE	1943-1980	94	87	137	175	151	114	132	116	106	95	99	110	868
MEAN	1943-1980	51	45	58	60	70	54	62	56	43	47	49	53	648
10 PERCENTILE VALUE	1943-1980	23	13	13	14	22	13	14	15	8	11	11	13	439
LOWEST MONTHLY/ANNUAL TOTAL	1943-1980	8	5	3	11	13	5	5	5	2	3	8	5	382
AVERAGE RAIN DAYS. 1.0MM OR MORE	1945-1980	6	5	7	7	8	8	9	7	6	7	7	7	84
MAXIMUM 1-DAY RAINFALL	1945-1980	110	-	102	75	62	55	77	51	73	33	45	80	110
MAXIMUM 2-DAY RAINFALL	1945-1980	121	72	109	116	78	84	94	81	81	63	65	82	121
TEMPERATURE OF THE AIR. DEGREES CELSIUS														
HIGHEST RECORDED	1953-1980	35.9	40.0	33.3	29.9	27.3	22.0	21.2	22.8	24.8	30.1	32.0	35.4	40.0
AVERAGE MONTHLY/ANNUAL MAXIMUM	1953-1980	32.1	31.8	29.1	25.9	21.3	17.8	17.2	19.5	21.7	25.5	27.6	30.1	33.5
AVERAGE DAILY MAXIMUM	1953-1980	22.0	21.9	19.8	17.3	13.8	11.1	10.4	11.9	14.4	16.9	19.2	20.6	16.6
MEAN	1953-1980	17.0	16.8	15.1	12.2	8.9	6.1	5.6	6.9	9.2	11.6	13.8	15.7	11.6
AVERAGE DAILY RANGE	1953-1980	10.0	10.3	9.5	10.2	9.9	10.1	9.7	10.0	10.3	10.5	10.8	9.9	10.1
AVERAGE DAILY MINIMUM	1953-1980	12.0	11.6	10.3	7.1	3.9	1.0	0.7	1.9	4.1	6.4	8.4	10.7	6.5
AVERAGE MONTHLY/ANNUAL MINIMUM	1953-1980	6.1	5.7	3.5	0.7	-2.0	-4.1	-4.4	-3.4	-1.7	0.0	2.2	4.8	-4.8
LOWEST RECORDED	1953-1980	3.1	2.7	-0.1	-4.0	-4.2	-7.2	-6.8	-6.7	-3.8	-4.2	-0.7	2.7	-7.2
TEMPERATURE OF THE GROUND. DEGREES CELSIUS														
LOWEST GRASS MINIMUM RECORDED	1953-1980	-0.6	-1.1	-3.4	-6.1	-8.8	-10.1	-9.4	-10.3	-7.9	-9.3	-4.7	-2.9	-10.3
AVERAGE GRASS MINIMUM	1953-1980	9.8	9.5	8.3	4.7	1.6	-1.4	-1.6	-0.6	1.3	3.3	5.5	8.4	4.1
AVERAGE AT 10 CM DEPTH	1959-1980	17.4	16.5	14.3	10.8	7.1	4.2	3.7	4.6	7.2	10.7	13.8	16.4	10.6
AVERAGE AT 30 CM DEPTH	1959-1980	18.9	18.7	16.5	13.4	9.6	6.3	5.5	6.5	8.8	11.9	14.9	17.6	12.4
AVERAGE AT 1 M. DEPTH	1959-1960	17.9	18.3	17.1	14.8	11.7	8.5	7.0	7.4	9.0	11.4	14.0	16.4	12.8
FROST.														
AVERAGE DAYS OF GROUND FROST	1953-1980	.	.	0.6	3.6	9.6	17.7	18.7	15.4	9.7	6.1	2.4	0.4	84.2
AVERAGE DAYS OF AIR FROST	1953-1980	.	.	.	0.5	4.1	12.6	13.3	9.5	3.8	1.0	0.1	.	44.9
RELATIVE HUMIDITY. (%)														
AVERAGE AT 9 A.M.	1953-1980	69	75	79	81	85	86	87	85	78	71	67	69	78
AVERAGE AT 3 P.M.	1960-1980	60	58	62	63	67	69	70	64	59	57	55	57	62
MEAN HOURLY	1960-1980	71	73	76	79	81	83	83	80	75	72	69	71	76
VAPOUR PRESSURE. MILLIBARS														
AVERAGE AT 9 A.M.	1953-1980	13.3	13.6	13.0	10.8	8.6	7.0	6.9	7.6	8.9	10.0	10.8	12.3	10.2
EVAPORATION. MILLIMETRES														
RAISED PAN AVERAGE	1964-1980	204	168	122	77	45	25	27	48	90	140	176	207	1329
SUNSHINE. TOTAL HOURS														
HIGHEST	1949-1980	288	244	227	202	164	160	172	195	220	244	265	264	2198
MEAN	1949-1980	209	186	163	150	125	120	122	145	162	200	207	210	1999
% OF POSSIBLE	1949-1980	46	50	44	48	44	47	45	47	48	51	49	46	47
LOWEST	1949-1980	148	112	80	95	93	83	61	100	90	149	151	124	1846
SOLAR RADIATION. MEGAJOULES/SQUARE METRE														
MEAN GLOBAL/DAY	1960-1980	21.8	19.5	13.8	9.7	6.2	4.9	5.3	8.1	12.4	17.9	21.5	23.3	13.7
WIND.														
AVERAGE DAYS OF GUSTS OF														
63 KM/HR OR MORE	1954-1980	5.9	4.2	4.3	4.1	4.1	3.3	2.7	3.1	4.1	5.4	6.0	4.3	51.5
96 KM/HR OR MORE	1954-1980	0.1	0.1	0.3	0.3	0.4	0.2	0.3	0.1	0.3	0.3	0.3	0.1	2.8
MEAN HOURLY WINDSPEED KM/HR	1942-1980	17	16	14	13	12	11	12	12	14	16	16	17	14
SPECIAL PHENOMENA. AVERAGE DAYS OF														
SNOW	1953-1980	.	.	.	.	0.2	0.5	0.7	0.4	0.5	0.1	.	.	2.4
HAIL	1953-1980	0.3	0.3	0.3	0.4	0.3	0.5	0.8	0.4	0.7	0.6	0.6	0.2	5.4
THUNDER	1955-1980	0.4	0.2	0.2	0.1	.	.	.	.	0.2	0.3	0.4	0.4	2.2
GALE	1953-1980	0.2	.	0.3	0.3	0.5	0.1	0.1	0.2	0.2	0.2	0.1	0.1	2.3
FOG	1953-1980	1.3	2.7	3.8	5.4	5.6	6.0	5.9	6.4	4.9	3.9	2.3	1.7	49.9

H32552 WIGRAM AERO

GRID REFS NZMS 1. 1 63360 S084924543 — NZMS 260. 1.50000 M36732399

LAT 43 33S LONG. 172 33E HT. 22 M.

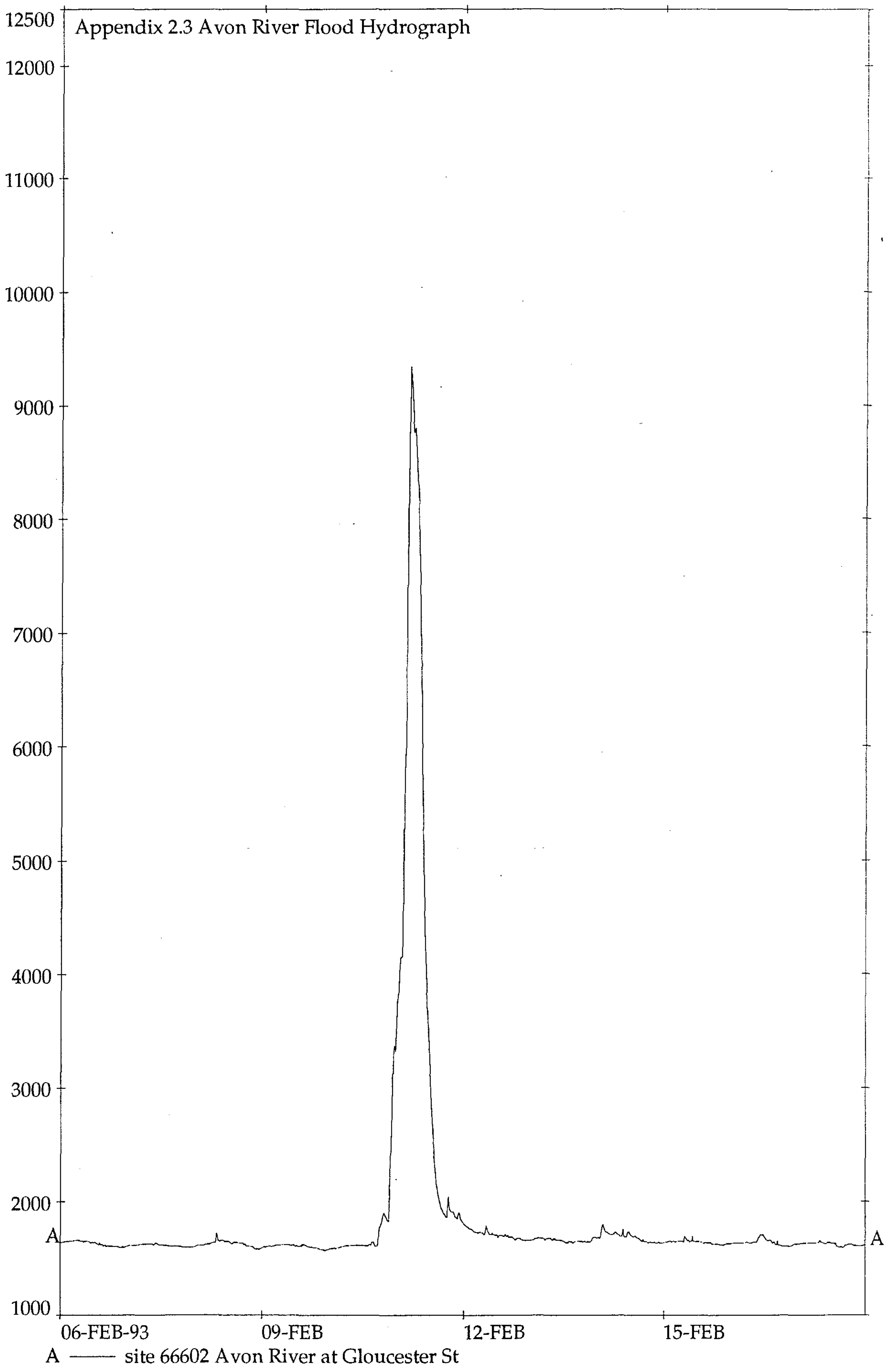
	PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
RAINFALL. MILLIMETRES														
HIGHEST MONTHLY/ANNUAL TOTAL	1938-1969	114	141	161	188	203	145	204	232	135	117	138	138	926
90 PERCENTILE VALUE	1938-1969	101	80	117	110	182	116	115	108	100	84	96	102	859
MEAN	1938-1969	56	44	52	58	75	55	62	54	45	42	50	55	648
10 PERCENTILE VALUE	1938-1969	26	12	16	23	19	15	18	15	7	12	14	7	454
LOWEST MONTHLY/ANNUAL TOTAL	1938-1969	9	5	11	13	11	5	6	7	5	2	11	5	390
AVERAGE RAIN DAYS. 1 0MM OR MORE	1937-1969	6	5	6	8	8	8	9	7	7	6	6	7	83
MAXIMUM 1-DAY RAINFALL	1937-1969	85	85	51	61	81	38	38	66	55	37	45	39	85
MAXIMUM 2-DAY RAINFALL	1937-1969	110	107	77	107	95	62	52	93	66	53	54	54	110
TEMPERATURE OF THE AIR. DEGREES CELSIUS														
HIGHEST RECORDED	1937-1968	35 8	34.7	33.7	29.3	27 3	22.1	20.9	22.6	25.4	28.1	31.2	32.8	35.8
AVERAGE MONTHLY/ANNUAL MAXIMUM	1937-1968	30.9	30.9	28.6	25.4	21.4	17.6	17.2	19 0	22.1	24 8	27.3	29.0	32.1
AVERAGE DAILY MAXIMUM	1937-1968	22.0	22.1	19 9	17.2	13.9	11 2	10.5	11.9	14.5	17 0	19.3	20.6	16.7
MEAN	1937-1968	16.6	16.8	14.9	12.0	9.0	6.2	5.7	7.0	9.3	11.6	13.7	15.4	11.5
AVERAGE DAILY RANGE	1937-1968	10.8	10.7	10.1	10.3	9.9	9.9	9.7	9 8	10.3	10.7	11.2	10.5	10.3
AVERAGE DAILY MINIMUM	1937-1968	11.2	11.4	9 8	6.9	4 0	1.3	0 8	2.1	4.2	6.3	8.1	10.1	6.4
AVERAGE MONTHLY/ANNUAL MINIMUM	1937-1968	5.3	4.7	2.8	0 3	-2.4	-3.7	-4.3	-3 5	-1.7	0.2	1.7	4.3	-4.8
LOWEST RECORDED	1937-1968	2.8	1.9	-0.1	-2.4	-5.3	-5.9	-9.4	-5.3	-4.8	-4.0	-2.2	-0.1	-9.4
TEMPERATURE OF THE GROUND. DEGREES CELSIUS														
LOWEST GRASS MINIMUM RECORDED	1937-1968	-2.3	-2.4	-4.1	-7.2	-8 9	-9.3	-11.1	-9.6	-10.4	-9.3	-6.7	-3.1	-11.1
AVERAGE GRASS MINIMUM	1937-1968	8 6	8.7	7.1	3.9	1.2	-1.4	-1 8	-1.1	0.8	3.1	4.8	7.3	3.4
FROST.														
AVERAGE DAYS OF GROUND FROST	1937-1969	0.2	0 2	1 6	5.2	10.1	16.2	17.4	15 9	10.7	5.7	2.8	0.4	86.4
AVERAGE DAYS OF AIR FROST	1937-1969	.	.	.	0.7	3 9	9.7	12.1	8.4	2.9	0.6	0.3	.	38.6
RELATIVE HUMIDITY. (%)														
AVERAGE AT 9 A.M.	1937-1969	65	70	77	82	85	87	87	83	76	68	65	67	76
WIND.														
AVERAGE DAYS OF GUSTS OF														
63 KM/HR OR MORE	1954-1971	4 9	4.7	4 1	3 7	3 9	2 8	2 9	2 3	3.3	4.4	5.6	4.2	46 8
96 KM/HR OR MORE	1954-1971	0.3	0.2	.	0.3	0 3	0.4	.	0.2	0.2	0.4	0.2	0.1	2.6
SPECIAL PHENOMENA. AVERAGE DAYS OF														
SNOW	1937-1969	.	.	.	.	0 2	0.4	1.0	0.4	0.4	0.2	.	.	2.6
HAIL	1937-1969	0 1	0 2	0 2	0 3	0 5	0 7	0.8	0.4	0.6	0 6	0.6	0.2	5 2
GALE	1937-1969	0 1	0 2	0.1	0 2	0 2	0.1	0.1	.	0.1	0 2	0.1	0.1	1.5
FOG	1937-1969	1 0	2.1	3 7	4 3	4 6	4 7	5.3	4.9	3.9	2.2	1.7	1.2	39.6

*H32561 CHRISTCHURCH

GRID REFS NZMS 1. 1:63360 S084990563 — NZMS 260. 1:50000 M35792419 — LAT 43 32S LONG 172 37E HT. 7 M

	PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
RAINFALL, MILLIMETRES														
HIGHEST MONTHLY/ANNUAL TOTAL	1894-1980	139	176	187	226	233	191	221	197	156	160	137	201	1010
90 PERCENTILE VALUE	1894-1980	110	87	134	109	169	122	145	99	97	95	84	119	856
MEAN	1894-1980	55	42	54	56	75	62	71	53	47	47	46	58	666
10 PERCENTILE VALUE	1894-1980	19	11	12	17	19	21	23	20	10	10	14	13	479
LOWEST MONTHLY/ANNUAL TOTAL	1894-1980	6	1	3	6	12	4	6	2	4	1	8	1	379
AVERAGE RAIN DAYS, 1.0MM OR MORE	1902-1980	7	5	7	7	8	9	9	7	7	7	7	7	87
MAXIMUM 1-DAY RAINFALL	1873-1980	105	78	90	124	102	75	80	83	56	69	46	108	124
MAXIMUM 2-DAY RAINFALL	1873-1980	120	95	130	149	122	130	105	112	76	130	66	110	149
TEMPERATURE OF THE AIR, DEGREES CELSIUS														
HIGHEST RECORDED	1864-1980	36.2	41.6	33.4	30.1	27.0	22.5	22.8	23.2	27.3	31.4	32.2	35.0	41.6
AVERAGE MONTHLY/ANNUAL MAXIMUM	1864-1980	30.6	29.7	28.0	24.8	20.9	17.3	16.9	18.4	21.8	24.9	26.7	29.1	31.9
AVERAGE DAILY MAXIMUM	1864-1980	21.5	21.1	19.4	16.9	13.5	10.8	10.3	11.6	14.3	16.9	18.9	20.6	16.3
MEAN	1864-1980	16.6	16.3	14.8	12.1	8.9	6.3	5.9	7.0	9.5	11.9	13.7	15.6	11.6
AVERAGE DAILY RANGE	1864-1980	9.9	9.6	9.3	9.5	9.2	9.0	8.9	9.1	9.6	10.1	10.4	10.0	9.5
AVERAGE DAILY MINIMUM	1864-1980	11.6	11.5	10.1	7.4	4.3	1.8	1.4	2.5	4.7	6.8	8.5	10.6	6.8
AVERAGE MONTHLY/ANNUAL MINIMUM	1864-1980	5.6	5.2	3.3	0.7	-1.7	-3.3	-3.4	-2.8	-1.1	0.5	2.2	4.6	-4.0
LOWEST RECORDED	1864-1980	1.1	1.2	-0.9	-3.6	-5.9	-5.8	-7.1	-5.0	-4.8	-3.3	-1.5	0.6	-7.1
TEMPERATURE OF THE GROUND, DEGREES CELSIUS														
LOWEST GRASS MINIMUM RECORDED	1864-1980	-4.9	-3.0	-6.2	-11.3	-11.5	-14.9	-12.1	-12.9	-11.7	-9.0	-6.9	-6.3	-14.9
AVERAGE GRASS MINIMUM	1864-1980	9.0	8.7	7.2	4.1	1.1	-1.3	-1.5	-0.9	1.2	3.2	5.1	7.6	3.6
AVERAGE AT 30 CM DEPTH	1936-1980	20.1	19.5	17.0	13.7	9.7	6.3	5.3	6.7	9.6	12.9	16.4	18.7	13.0
AVERAGE AT 1 M. DEPTH	1936-1980	18.8	19.0	17.6	15.1	11.8	8.7	7.1	7.7	9.7	12.3	15.2	17.3	13.4
FROST.														
AVERAGE DAYS OF GROUND FROST	1864-1980	0.2	0.2	1.1	4.5	11.2	17.8	18.8	16.8	10.0	5.2	2.4	0.5	88.7
AVERAGE DAYS OF AIR FROST	1864-1980	.	.	.	0.5	3.4	10.0	11.3	7.8	2.2	0.4	0.1		35.7
RELATIVE HUMIDITY, (%)														
AVERAGE AT 9 A.M.	1928-1980	70	73	79	85	87	89	89	96	76	69	66	69	78
VAPOUR PRESSURE, MILLIBARS														
AVERAGE AT 9 A.M.	1941-1980	13.7	13.9	13.4	11.5	9.2	7.5	7.3	8.1	9.3	10.3	11.3	12.8	10.7
SUNSHINE, TOTAL HOURS														
HIGHEST	1935-1953	252	234	266	192	183	162	176	182	195	237	259	242	2200
MEAN	1935-1953	211	183	180	139	126	114	127	145	164	185	205	195	1974
% OF POSSIBLE	1935-1953	47	49	49	45	45	45	47	47	49	47	48	42	47
LOWEST	1935-1953	142	133	121	80	80	72	87	90	104	143	152	115	1873
SPECIAL PHENOMENA, AVERAGE DAYS OF														
SNOW	1867-1980	.	.	.	.	0.2	0.5	0.8	0.4	0.3	0.2			2.4
HAIL	1867-1980	0.3	0.1	0.2	0.4	0.4	0.5	0.5	0.4	0.6	0.4	0.4	0.3	4.5
THUNDER	1955-1980	0.4	0.1	0.2	.	0.1	0.1	0.1		0.1		0.2	0.2	1.5
GALE	1867-1980	0.9	0.8	0.5	0.6	0.7	0.5	0.3	0.6	0.9	1.0	1.1	1.0	8.9
FOG	1928-1980	0.2	0.5	1.2	1.8	3.2	3.8	3.2	2.4	0.9	0.3	0.3	0.3	18.1

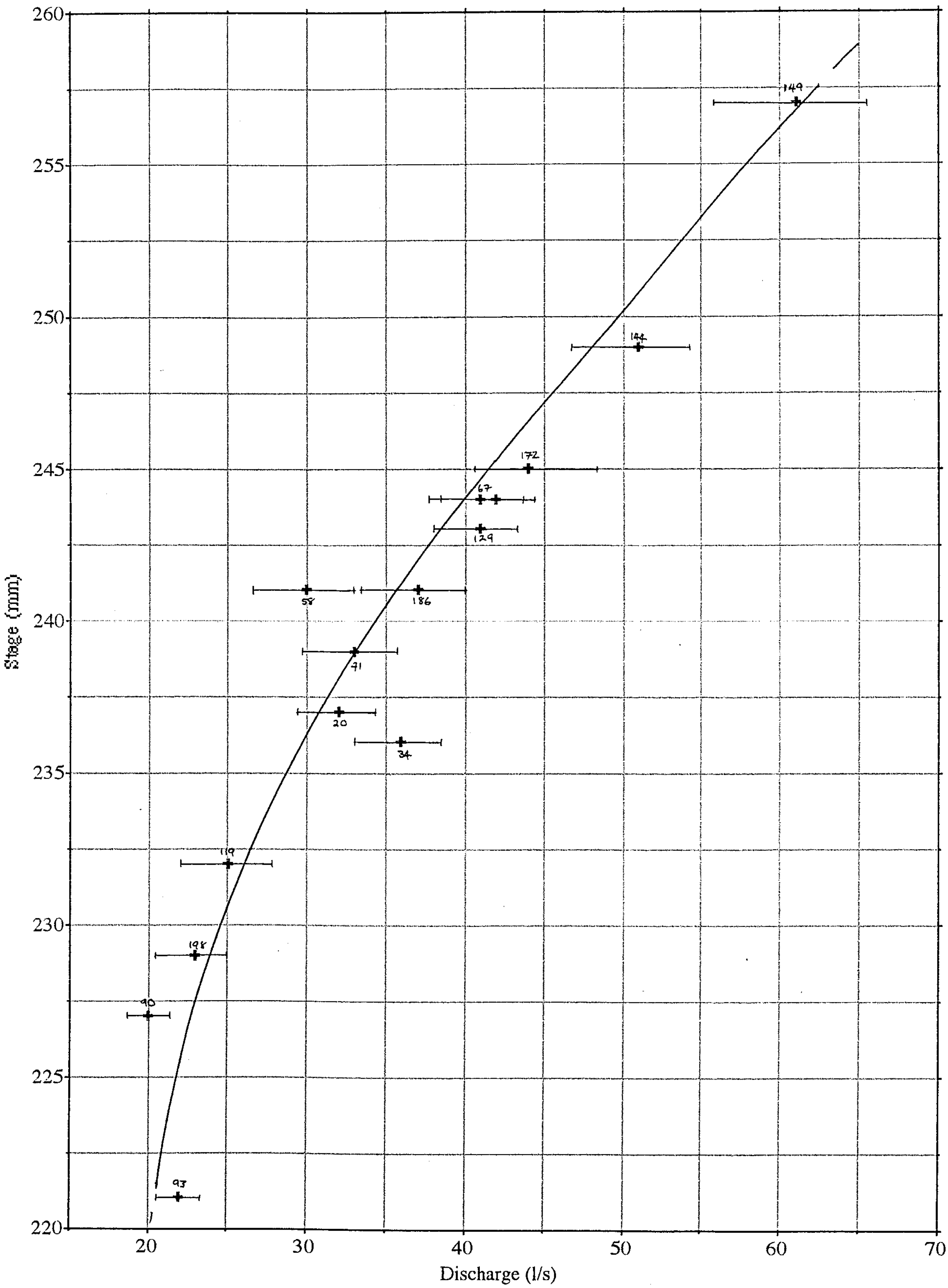
*INCLUDES OBSERVATIONS FROM VARIOUS SITES IN CHRISTCHURCH FROM 1864-1905


Appendix 2.3 Avon River Flood Hydrograph
12500
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
A
A
06-FEB-93
09-FEB
12-FEB
15-FEB
A —— site 66602 Avon River at Gloucester St

Appendix 3.2 Addington Drain at Hagley Park Site 66635							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Discharge (l/s)
920216	133500		244				42
920227	144000	20	237	32	12.5	4	32
920305	131000	32	236	36	12.5	5	30
920308	181000		241				38
920310	172000	41	239	33			35
920320	165000	58	241	30	16.8	5	38
920325	156000	67	244	41	12	5	42
920305	152000		243				41
920308	151000		241				38
920413	102000		242				39
920415	143000	90	227	20	9.3	2	22
920422	145000		247				47
920424	163000		267				75
920427	163500	93	221	22	8.2	2	19
920429	160000		238				33
920430	150500		239				35
920505	141500		250				51
920511	151500		241				38
920513	162500		232				25
920516	155500		232				25
920518	110000		230				24
920521	164500		236				30
920526	134000		237				32
920529	145500		230				24
920602	171500		236				30
920604	130500		230				24
920611	143000	119	232	25	18.3	5	25
920615	130000		242				39
920618	150000		233				27
920623	150500		230				24
920626	153500		232				25
920629	120000		232				25
920702	151500		233				27
920707	140000		230				24
920710	133000		247				47
920714	101500	129	243	41	15.4	6	41
920720	121000		243				41
920727	123500		236				30
920729	164500		236				30
920731	161500		238				33
920807	143000	144	249	51	13.3	7	50
920811	165000		235				29
920821	144900		241				38
920902	930000	149	257	61	12.7	7	61
920904	114000		248				48
920913	165000		254				57

Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Discharge (l/s)
920922	135000		240				36
920925	162500		256				60
921001	124500	172	245	44	15.1	7	44
921007	121500		242				39
901012	133500		240				36
921021	130500		238				33
921030	121000		235				29
921103	123500		231				25
921105	125500	186	241	37	17.7	6	38
921109	135000		235				29
921124	125000		229				23
921209	141500	198	229	23	17.6	4	23
921222	112000		240				36
930107	155000		235				29

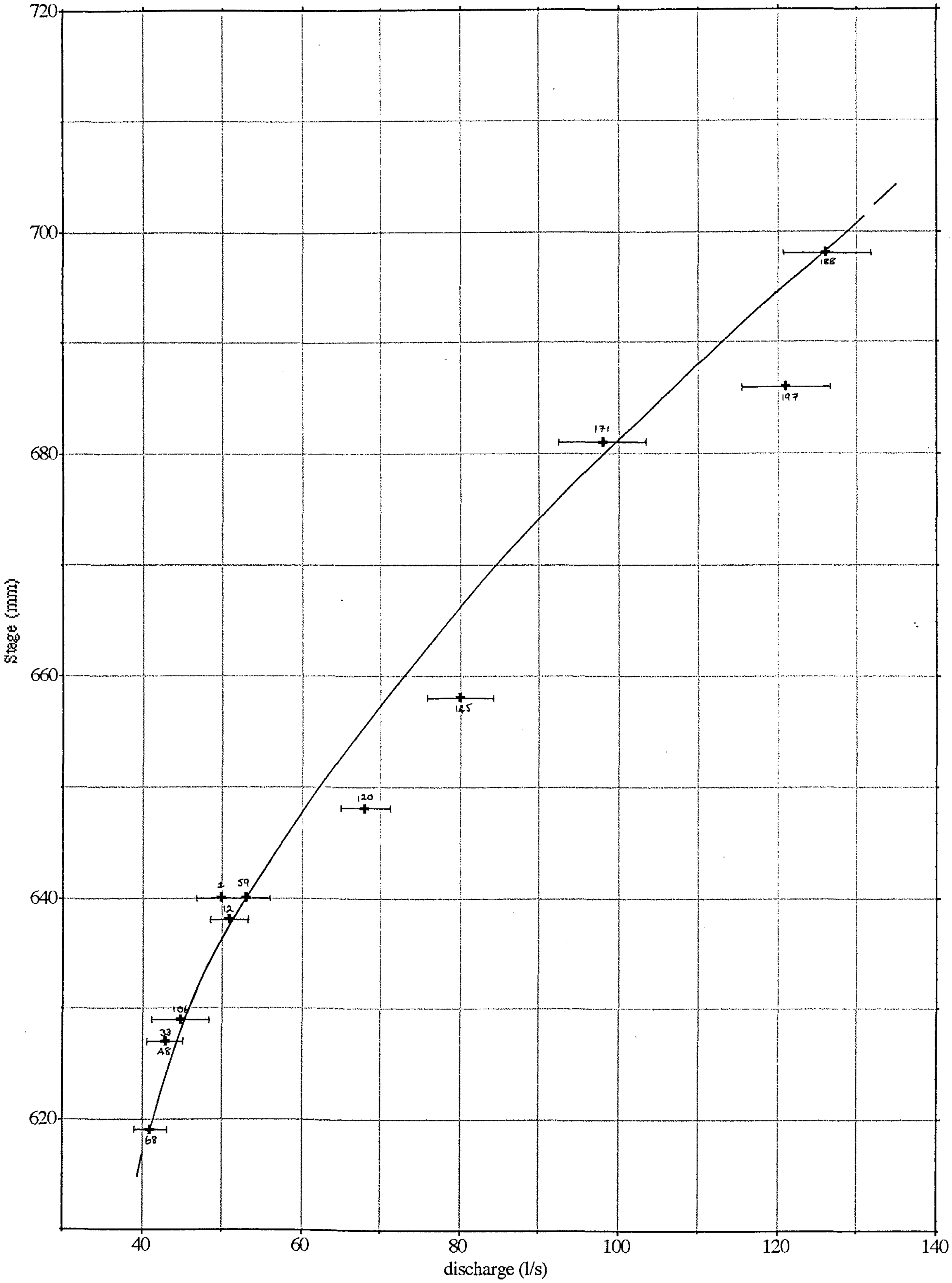
Rating Curve - Addington Drain at Hagley Park



Appendix 3.3 Riccarton Drain at Riccarton Ave Site 66636							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920216	112500	1	648	50	11.5	6	44
920226	154500	12	638	51	10.1	5	44
920306	135000	33	627	43	9.8	4	44
920308	181500		626				44
920310	132500	48	627	43	9.9	4	49
920320	173000	59	640	53	9.6	5	41
920325	150500	68	619	41	9.8	4	49
920408	151500		635				48
920413	163000		637				50
920415	144500		634				47
920422	144500		640				53
920424	163500		639				52
920427	165000		668				86
920430	151000		657				71
920505	142000		662				77
920511	152000		647				60
920513	163000		633				47
920516	160000		641				54
920518	110500	106	629	45	9.8	5	45
920521	164000		636				49
920526	134500		644				57
920529	150000		640				53
920602	172000		638				51
920604	131000		633				47
920611	150000	120	648	68	9.4	6	61
920615	130500		653				66
920618	145500		651				64
920623	150000		655				69
920626	154000		646				59
920629	121000		651				64
920702	151000		652				65
920707	135500		659				74
920710	131500		659				74
920714	104500		653				66
920720	115500		658				72
920727	124000		654				68
920729	165000		651				64
920731	162000		650				63
920807	125500	145	658	80	10.1	8	72
920811	164500		655				69
920821	145300		649				62
920902	100500		706				138
920904	113500		670				88
920913	155000		716				155

Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920922	134500		682				104
920925	162000		692				118
921001	121000	171	681	98	10.1	10	103
921007	121000		691				116
901012	140000		693				119
921021	131000		690				115
921030	121500		700				129
921105	125500	185	698	126	9.1	12	126
921109	134500		695				121
921124	131500		690				115
921209	134000	197	686	121	9.1	11	110
921222	111500		671				90
930107	155500		679				100

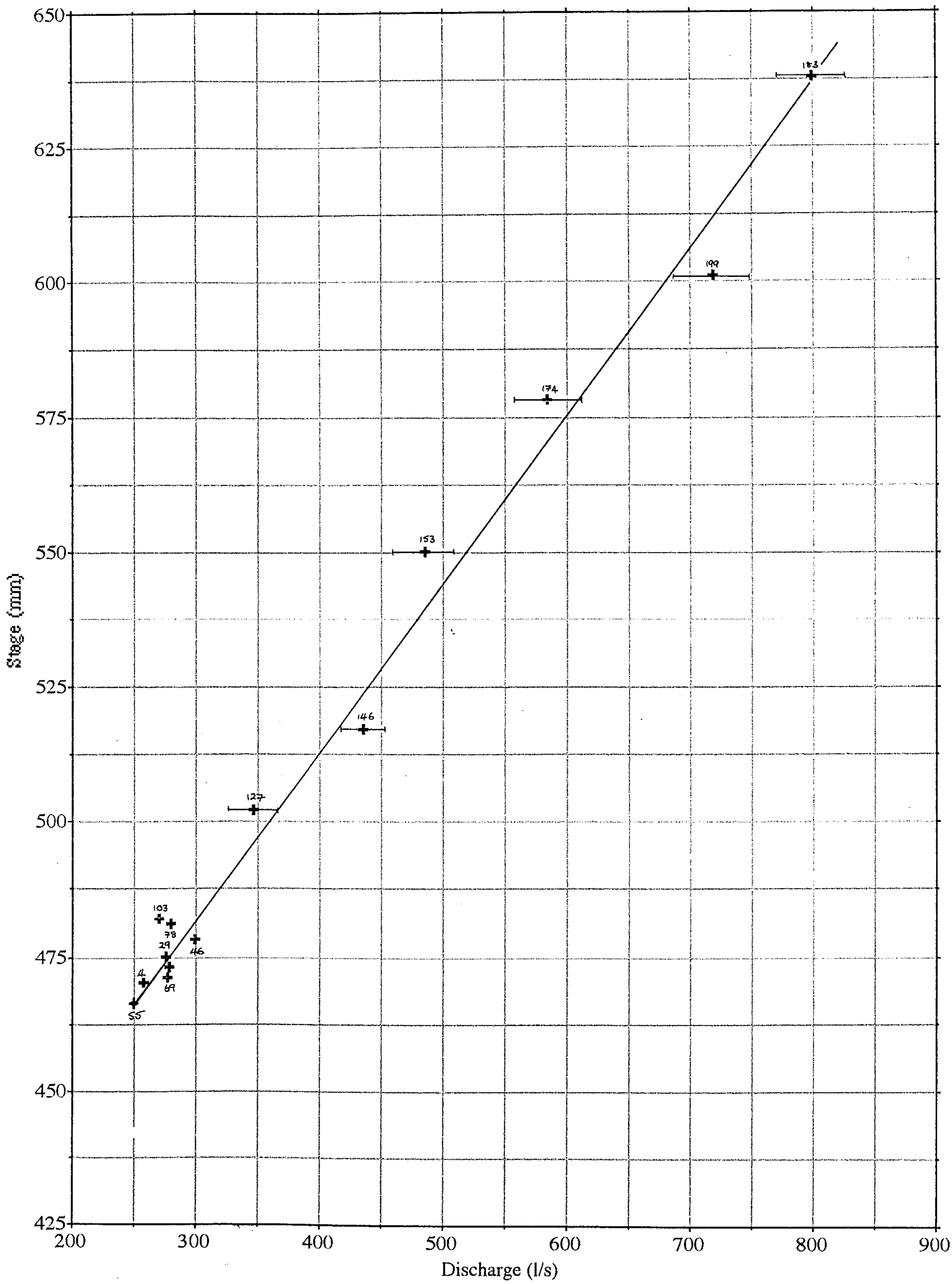
Rating Curve - Riccarton Drain at Riccarton Avenue



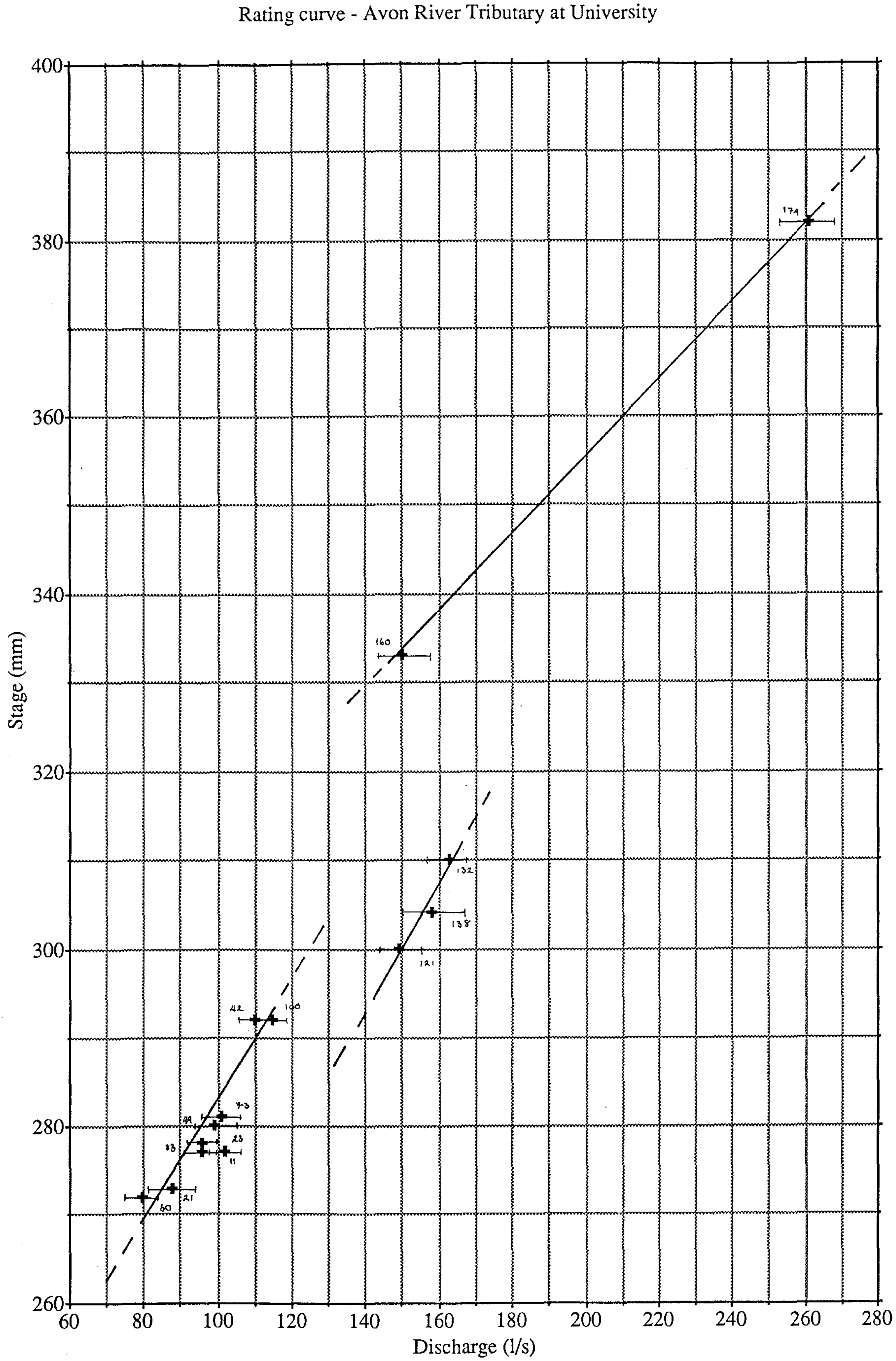
Appendix 3.4 Avon River at Harakeke Street Site 66637							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920220	135500	4	470	258	9.1	23	254
920226	164000	13	473	279	8.8	25	264
920305	142500	29	475	277	11	30	270
920308	154500		469				251
920310	125000	46	478	300	9	27	280
920320	145000	55	442	251	10.1	25	165
920325	170000	69	471	278	8.6	24	257
920327	134000		471				257
920405	143000	78	481	280	8.6	24	289
920408	144800		476				273
920413	103500		471				57
920415	145500		470				254
920422	144000		476				273
920424	170000		480				286
920427	141000		477				276
920428	151000		480				286
920430	152500		480				286
920505	135000		491				321
920511	144500		490				318
920513	152000		482				292
920516	161500		484				299
920518	114000	103	482	271	7.4	20	292
920521	162000		502				356
920526	133500		509				379
920529	143000		495				334
920602	165500		490				318
920604	130000		488				312
920611	153500		502				356
920615	131500		502				356
920618	152000		502				356
920623	145500		501				353
920626	154500		501				353
920729	113000		502				356
920702	150000		502				356
920703	145000	127	502	347	10.5	36	356
920707	131500		504				363
920710	140500		510				382
920714	152500		515				398
920720	114000		501				353
920727	121500		516				401
920729	165500		516				401
920731	163000		519				411
920807	133500	146	517	436	6.9	30	405
920811	171000		516				401

Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920821	145800		532				453
920902	120000	153	550	486	9.3	45	511
920904	111500		541				482
920913	162500		549				508
920922	134000		557				534
920925	161500		560				544
921001	135500	173	578	585	8.8	51	602
921007	122500		596				661
921012	140500		610				707
921021	132000		621				744
921030	135500		633				783
921102	123000	183	638	800	8.8	63	800
921109	140500		633				783
921124	132500		627				765
921209	144000	199	601	719	8.7	70	678
921222	131000		580				609
930107	160000		560				544

Rating Curve - Avon River Tributary at Harakeke Street



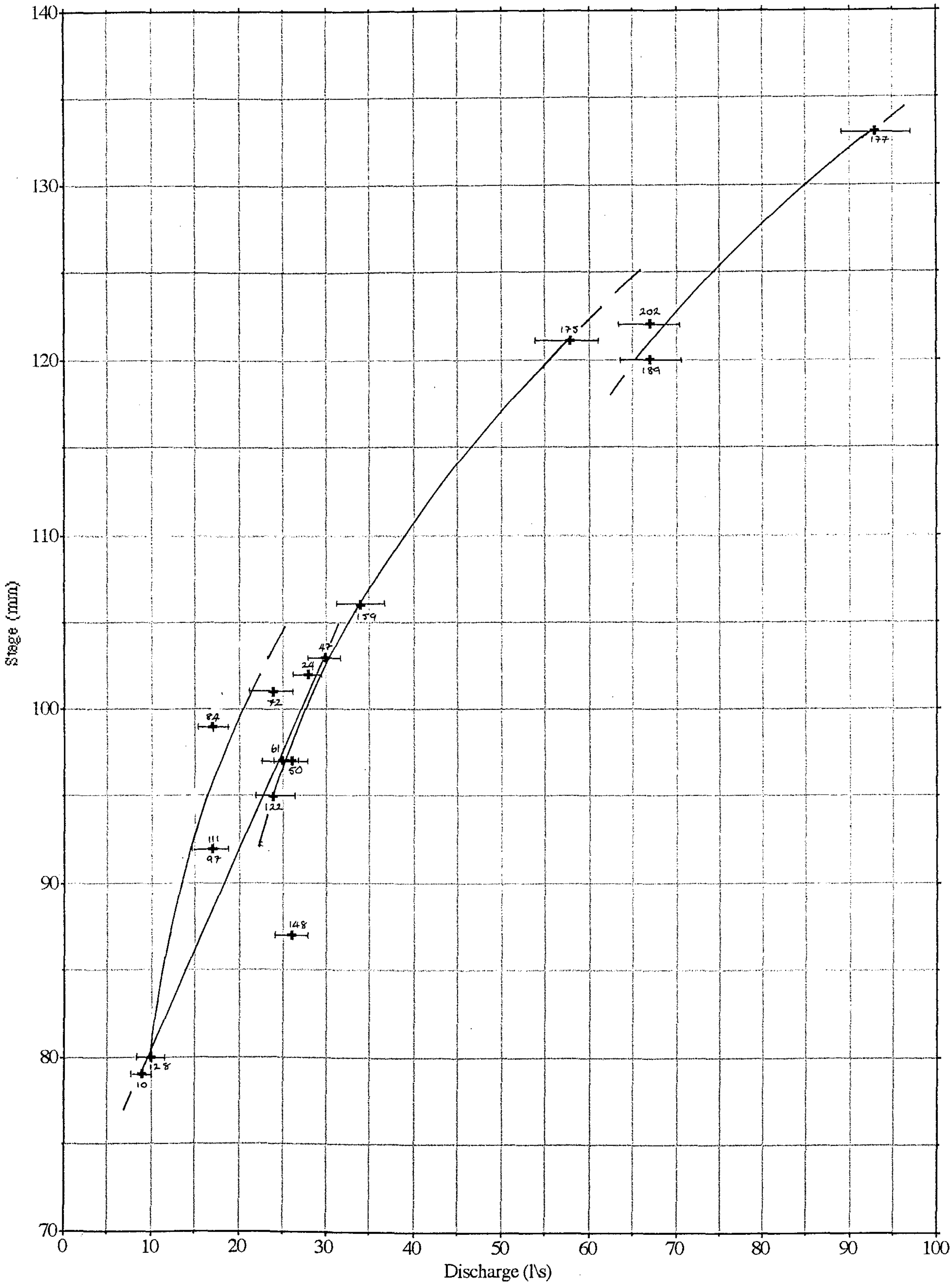
Appendix 3.5 Avon River Tributary at University Site 66638							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920223	161500	11	281	101	10.1	10	99
920227	153000	21	273	88	10.6	9	90
920305	80000	23	278	96	9.5	9	96
920310	72500	42	292	110	9.7	9	110
920320	85000	49	280	99	9.7	9	98
920325	80000	60	272	80	9.7	8	89
920405	103000	73	277	102	9.2	9	95
920408	152500		280				98
920413	112500		276				94
920415	83000	83	277	96	8.2	8	95
920422	162000		270				85
920424	173500		274				91
920427	110500		278				96
920428	115500		275				93
920430	162000		275				93
920505	143000		276				94
920511	160500		285				102
920513	164000		285				99
920516	165500		281				97
920518	85500	100	292	115	9.8	11	110
920526	143500		294				112
920529	151000		288				105
920602	173000		295				114
920603	165500		290				107
920611	170000	121	300	149	8.3	12	150
920615	140500		296				146
920618	165000		296				146
920623	154500		289				148
920626	165000		296				146
920629	122500		296				146
920702	154500		298				148
920707	125000		300				150
920710	114000		302				152
920714	121500	132	310	163	9.5	15	160
920720	105000		281				130
920727	125000		303				153
920729	171000		300				150
920731	165000		301				151
920807	90000	138	304	158	7.7	12	154
920809	143000		307				157
920811	163500		304				154
920821	141200		312				162
920902	160500	160	333	150	11.1	17	148
920904	95500		334				149
920913	145500		348				167
920922	112000		346				164
920925	135000		361				185
921001	90500	174	382	261	7.7	17	219


Rating curve - Avon River Tributary at University
Stage (mm)
Discharge (l/s)
400
380
360
340
320
300
280
260
60
80
100
120
140
160
180
200
220
240
260
280
174
160
132
138
121
42
100
73
89
23
83
11
21
60

Appendix 3.6 Okeover Stream at University Site 66640							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920223	153000	10	79	9	12.5	1	9
920227	161000	22	95	24	11	3	23
920305	84500	24	102	28	11.3	3	29
920308	132000		74				5
920311	115000	47	103	30	10.5	3	30
920320	93000	50	97	26	10.5	3	25
920325	84500	61	97	25	10.3	3	25
920405	94500	72	101	24	10.5	3	22
920408	153000		112				35
920413	170000		116				41
920415	91000	84	99	17	11	2	20
920422	162500		111				33
920424	173000		101				22
920427	110000		93				16
920430	161500		84				12
920505	131500		86				12
920511	141500		98				19
920513	140500	97	92	17	11.5	2	16
920516	165000		79				10
920518	124500		80				10
920521	134500		80				10
920526	143000		87				13
920529	151500		84				12
920603	165000		82				11
920604	115000		86				12
920611	93000	111	92	17	14.3	3	16
920615	140000		80				10
920618	164500		90				14
920623	152500		90				14
920626	162500		91				15
920629	123000		91				15
920702	155000		89				14
920707	124500		82				11
920710	113500		87				13
920714	93000	128	80	10	16.7	2	10
920720	104500		88				13
920727	124500		95				17
920729	171200		95				17
920731	165500		98				19
920807	110000		86				12
920809	162000	148	87	26	11.4	3	13
920811	140000		85				12
920821	141500		93				16
920902	153500	159	106	34	11	4	34

Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920904	160000		102				30
920913	145000		111				40
920922	111500		115				47
920925	135500		130				78
921001	93000	175	121	58	9.7	6	58
921007	115000		131				81
921012	142000		136				94
921021	104500		132				90
921029	103000	177	133	93	9.4	9	93
921103	112000		133				93
921112	90000		135				94
921124	101500		122				68
921207	113500	189	120	67	9.8	7	64
921222	102000		116				57
930107	145000		120				64
930111	125500	202	122	67	9.9	7	68

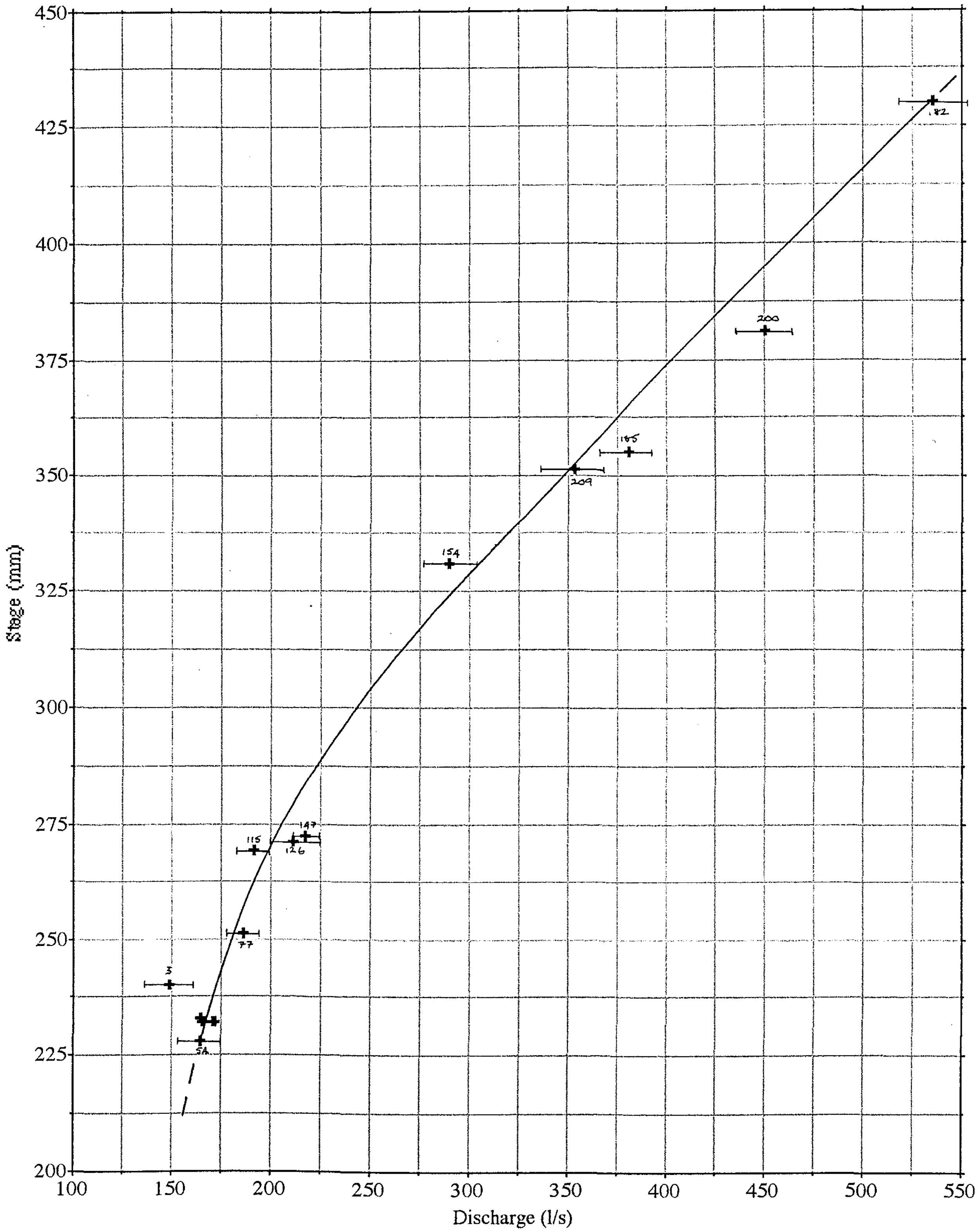
Rating Curve - Okeover Stream at University



Appendix 3.7 Waimairi Stream at Daresbury Park Site 66641							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920216	153000	3	240	149	8.6	13	172
920227	120000	16	232	172	8.8	15	167
920305	142000	28	232	166	10.6	18	167
920308	154000		231				167
920310	141500	38	232	171	10.6	18	167
920320	134500	54	228	165	10.1	17	165
920325	171000		232				167
920327	133000	71	233	165	8.6	14	168
920405	134000	77	251	187	8.6	16	180
920408	144500		250				179
920413	110000		247				176
920415	145500		247				176
920422	142000		254				182
920424	170000		247				176
920427	141000		252				180
920429	151000		246				176
920430	152500		247				176
920505	135000		250				179
920511	144500		265				192
920513	152000	98	269	192	9	17	197
920516	161500		267				195
920518	114000		271				199
920521	162000		242				173
920602	165200		267				195
920604	125500		277				207
920611	115000	115	269	192	6.8	13	197
920615	132000		273				201
920618	152500		275				204
920623	145000		270				198
920626	155000		271				199
920729	173000		270				198
920702	145500		271				199
920703	140500	126	271	212	11	23	199
920707	131000		270				198
920710	141000		278				208
920714	153000		271				199
920720	113500		271				199
920727	121000		279				209
920729	170000		280				211
920731	163500		282				214
920807	141000	147	272	218	7.1	15	200
920811	171500		274				203
920821	150100		290				227
920902	123500	154	331	290	9	26	307

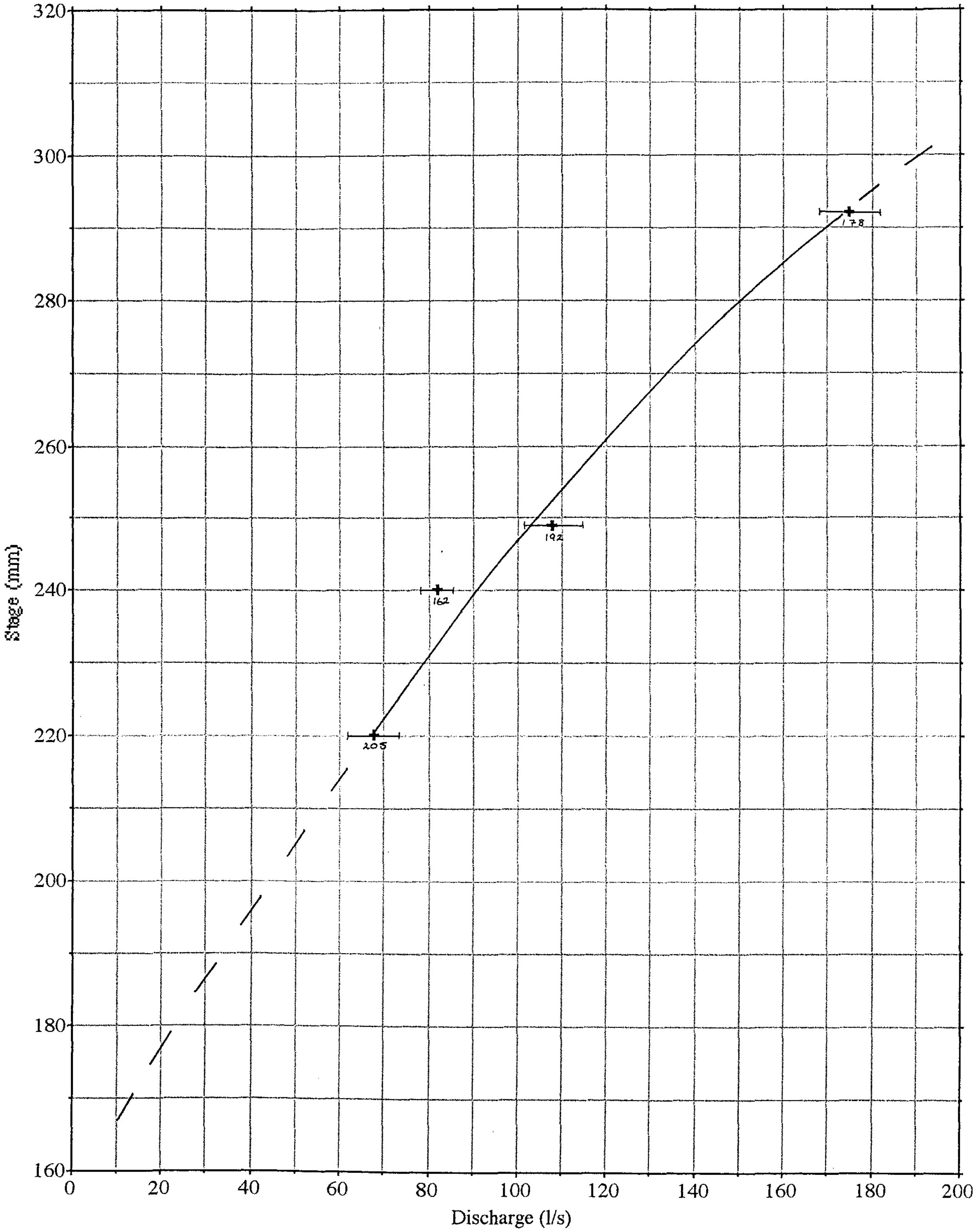
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920904	111000		321				285
920913	163000		339				325
920922	133500		350				350
920923	131500	165	355	381	7.6	29	361
920925	161000		370				395
921001	134000		382				422
921007	123000		401				467
921012	141000		414				498
921021	132500		422				517
921030	135000		430				536
921102	121000	182	430	536	6.7	36	536
921109	141000		420				512
921124	133000		399				462
921209	154500	200	381	451	6.4	29	420
921222	131500		370				395
930107	160500		361				374
930115	153000	209	351	354	9	31	352

Rating Curve - Waimairi Stream at Daresbury Park



Appendix 3.8 Waimairi Stream at Coldstream Crt Site 66644							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920223			157	dry			0
920305			157	dry			0
920325			158	1			1
920405			158	1			1
920513			158	1			1
920516			158	1			1
920518			158	1			1
920603			158	1			1
920629			163	6			6
920714			165	8			8
920730			176	12			12
920811			170	15			15
920923	122000	164	240	82	7.4	6	89
920925	140500		240				89
921001	133500		260				115
921007	133500		274				138
921012	143100		286				160
921021	171000		296				199
921029	113000	178	291	175	6.8	12	174
921103	114100		289				167
921109	114000		280				148
921124	104500		272				134
921207	132500	192	249	108	7.4	8	100
921222	103600		236				84
930107	151000		227				74
930112	130000	205	220	68	11.5	8	68

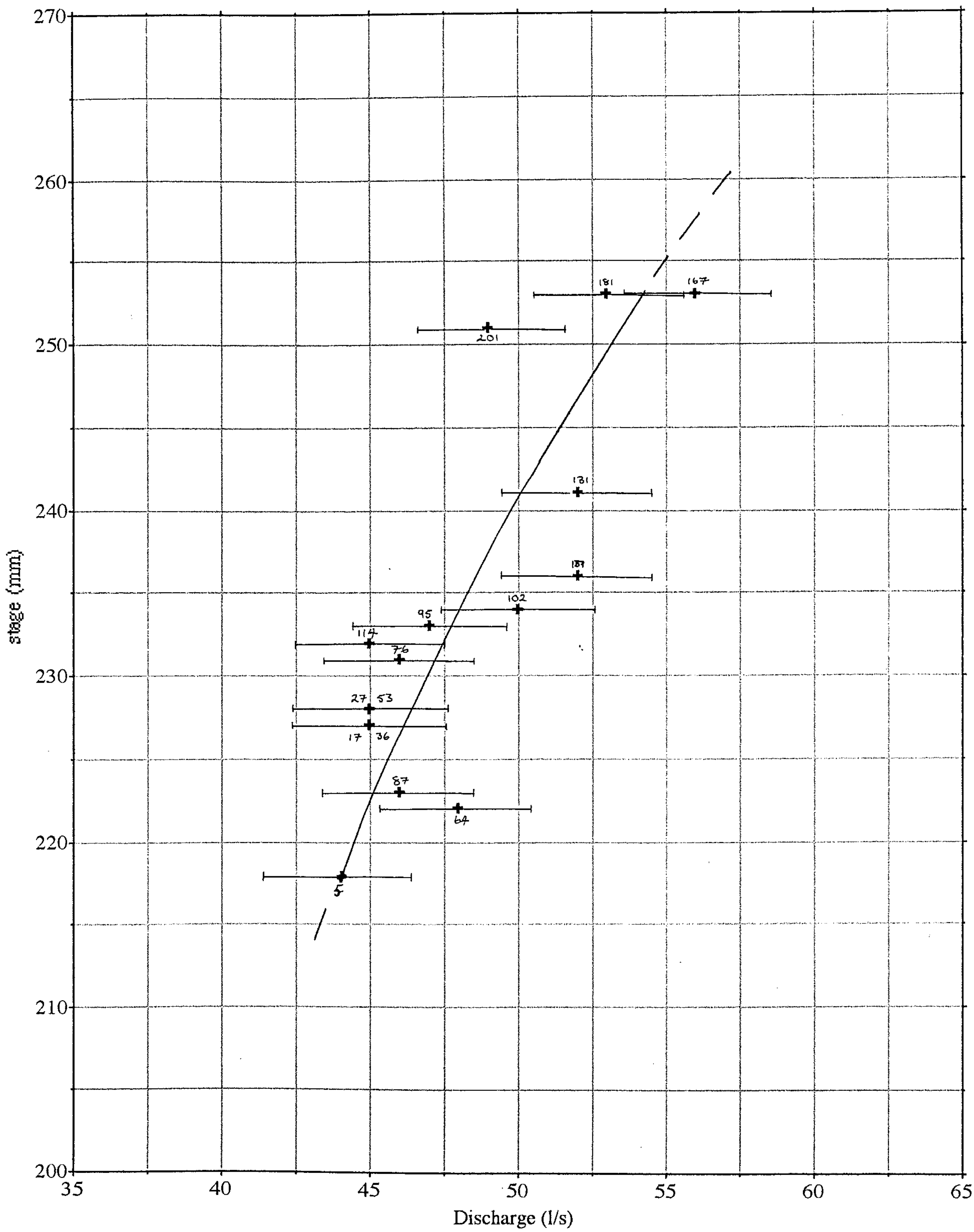
Rating Curve - Waimairi Stream at Coldstream Court



Appendix 3.9 Drain 23 at 7 Royds Street Site 66642							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920220	144500	5	218	44	11	5	44
920227	123000	17	228	45	11	5	47
920305	134000	27	229	45	11.5	5	47
920310	131500	36	228	45	11	5	47
920320	130500	53	229	45	10.1	5	47
920325	123000	64	222	48	10.1	5	45
920327	133500		222				45
920405	130000	76	230	46	10.1	5	47
920408	144000		225				46
920415	114500	87	222	46	10.6	5	45
920422	142500		225				46
920424	170500		224				46
920427	140500		226				46
920430	153000		230				47
920505	134500		230				47
920511	144000		236				49
920512	113000	95	233	47	11.5	5	48
920513	151500		232				48
920516	161500		233				48
920518	101000	102	234	50	9.7	5	48
920521	161500		238				49
920526	132500		236				49
920529	142000		260				57
920602	165000		250				53
920604	125000		249				53
920611	112000	114	232	45	10.4	5	48
920615	132500		231				47
920618	153000		233				48
920623	144500		232				48
920626	155500		232				48
920729	172500		232				48
920702	145000		232				48
920707	130500		235				48
920710	141500		240				50
920714	113000	131	236	52	9.7	5	49
920720	113000		237				49
920727	120500		238				49
920729	170500		240				50
920731	164000		240				50
920807	134000		231				47
920811	172000		232				48
920821	154000		229				47
920902	130500	155	241	52	10.2	5	50
920904	110500		241				50

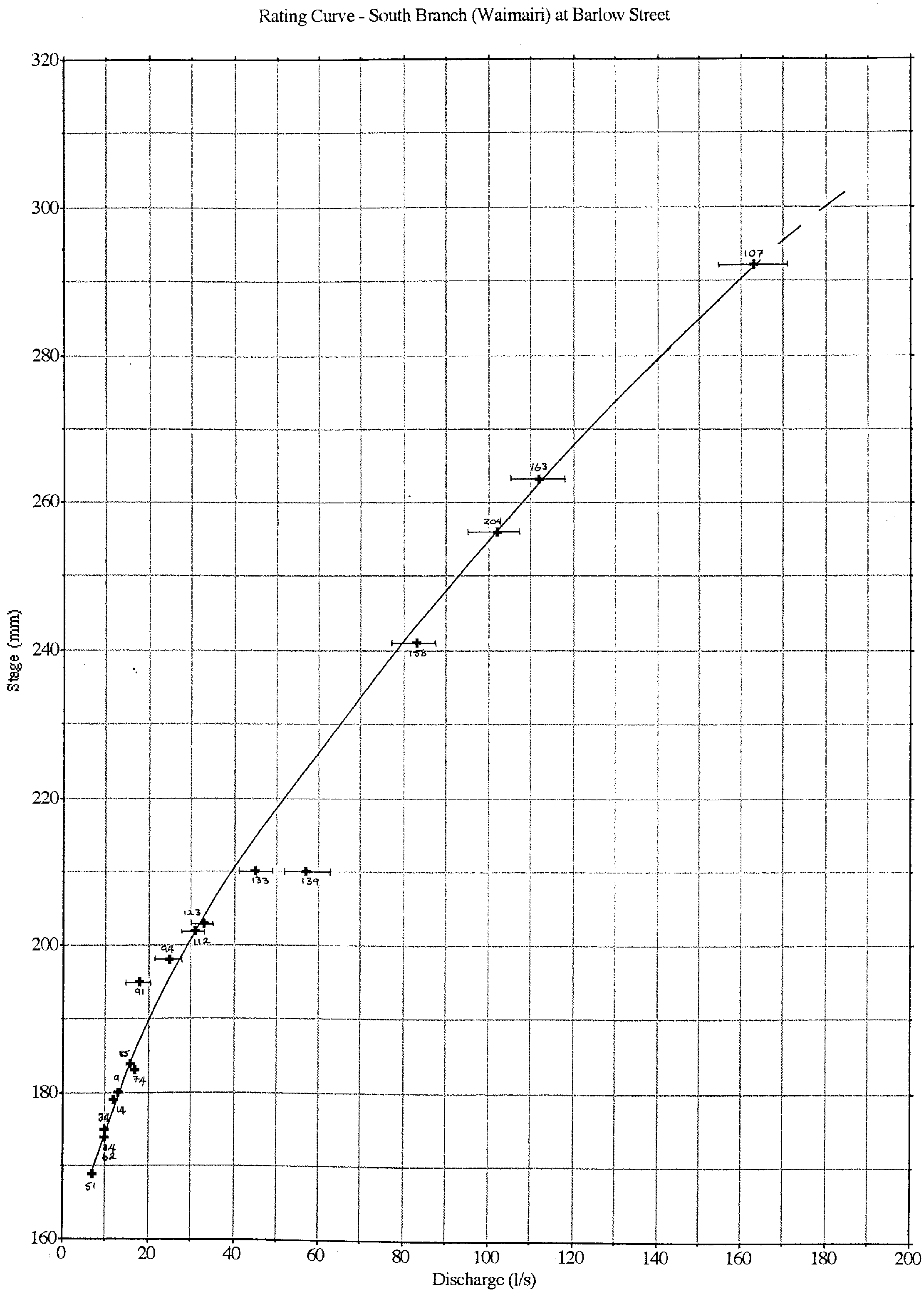
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920914	151500		251				53
920922	133000		243				51
920925	151000	167	253	56	10.4	5	54
921001	135000		253				54
921007	123500		260				57
921012	141500		251				53
921021	133000		251				53
921030	143000	181	253	53	9.9	5	54
921102	114000		251				53
921109	141500		251				53
921124	133500		243				51
921209	162500	201	251	49	10	5	53

Rating Curve - Drain 23 at 7 Royds Street



Appendix 3.10 South Branch at Barlow Street Site 66643							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920223	144500	9	180	13	12.5	2	13
920227	95500	14	179	12	12.5	2	12
920305	115000	25	174	10	13.5	1	9
920308	141000		176				11
920310	90000	34	175	10	12.5	1	10
920320	113000	51	169	7	16.8	1	7
920325	103500	62	174	10	13.5	1	9
920405	111500	74	183	17	11.5	2	15
920408	135500		182				14
920413	113500		183				15
920415	100000	85	184	16	8.2	1	16
920422	113000		191				21
920424	172000		191				21
920427	124500	91	195	18	8.3	2	24
920430	161000		197				26
920505	132000		200				29
920511	142000		198				27
920512	104500	94	198	25	8.1	2	27
920516	164500		198				27
920518	121500		198				27
920521	155000		200				29
920526	142500		201				30
920529	140000		201				30
920602	162500		197				26
920604	120500		197				26
920611	100500	112	202	31	12.5	4	31
920615	135500		204				33
920618	162000		204				33
920623	120000		203				32
920626	162000		204				33
920629	102000	123	203	33	11.5	4	32
920702	125000		204				33
920707	160000		202				31
920710	150000		207				36
920714	130000	133	210	45	11.2	5	40
920720	110000		210				40
920727	114500		211				41
920729	151500		211				41
920731	151000		210				40
920803	120000		209				49
920807	112500	139	210	57	10.1	6	40
920811	173500		210				40
920821	142000		219				51
920902	150000	158	241	83	9.9	8	80

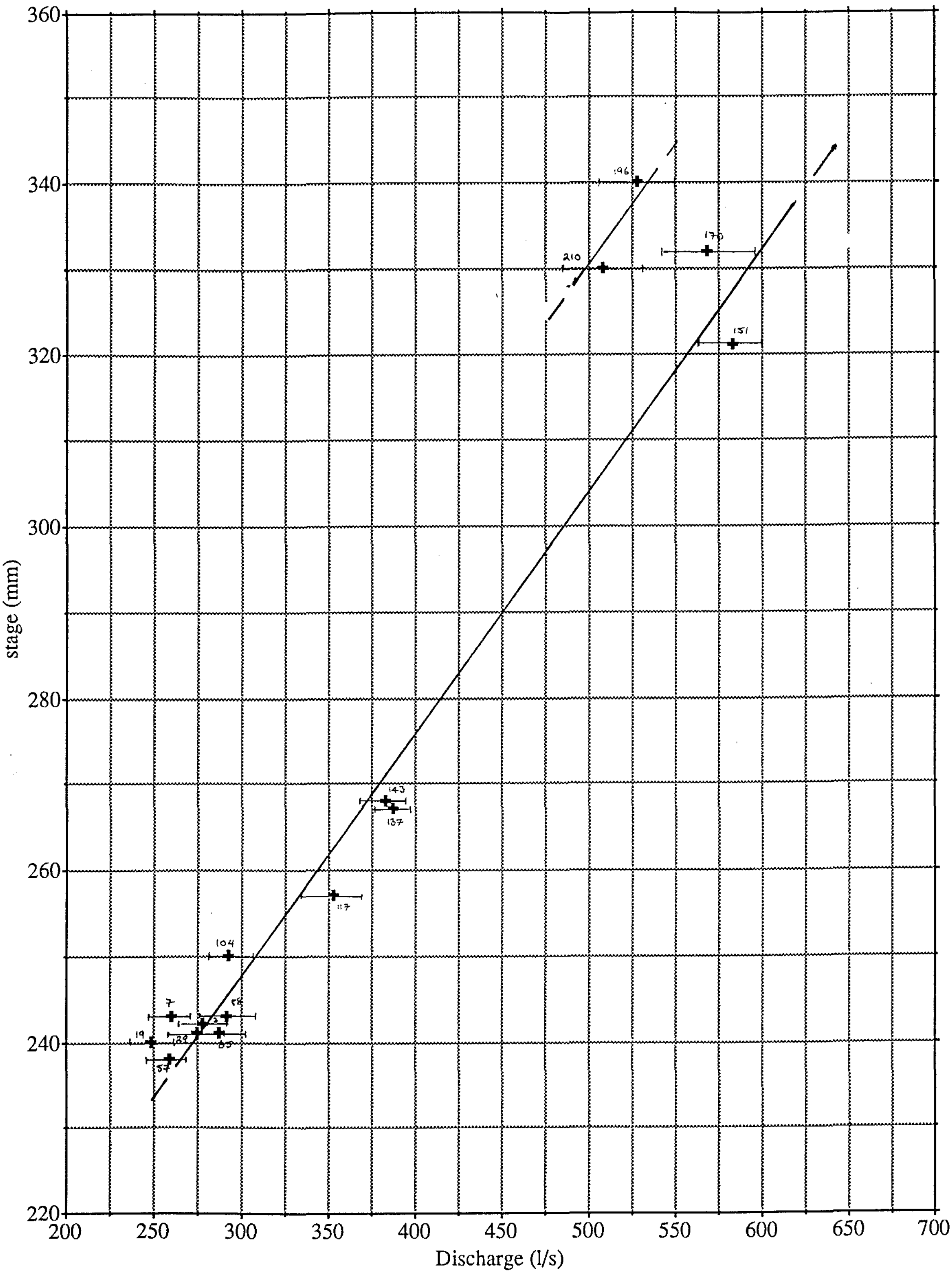
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920904	105000		240				79
920913	164500		251				94
920922	114000		260				108
920923	111500	163	263	112	9.2	10	113
920925	140000		260				108
921001	155000		271				127
921007	133500		280				142
921012	143000		291				161
921016	151500		290				159
921021	170500		291				161
921022	113500	176	292	163	8.9	15	163
921029	113500		293				165
921103	114000		288				156
921109	115500		285				151
921124	104000		279				140
921207	115500		271				127
921222	10500		265				116
930107	150000		258				105
930112	124000	204	256	102	10.1	10	102


Rating Curve - South Branch (Waimairi) at Barlow Street
Stage (mm)
Discharge (l/s)
320
300
280
260
240
220
200
180
160
0
20
40
60
80
100
120
140
160
180
200
107
163
204
158
133
139
123
112
94
91
85
9
74
14
34
24
62
51

Appendix 3.11 Wairarapa Stream at Garden Rd Site 66645							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920222	135000	7	243	260	9	23	278
920227	140000	19	240	249	9	22	267
920306	111500	31	242	278	8.6	24	274
920308	155500		242				274
920310	153500	39	242	275	8.8	24	270
920320	161000	57	238	259	8.6	22	259
920325	132000	65	241	287	8.8	25	270
920327	134500		224				203
920405	144000		253				315
920408	145500		247				293
920413	161500		244				278
920415	130000	88	244	292	7.6	22	278
920422	140500		242				274
920424	165000		241				270
920427	143000		240				267
920430	145000		240				267
920505	140000		251				308
920511	145500		258				334
920513	160500		248				297
920516	153500		256				327
920518	114000	104	250	293	6.5	19	304
920521	162500		253				315
920526	132000		259				338
920529	143500		258				334
920602	170000		245				285
920604	124500		250				304
920611	131000	117	257	353	7	24	331
920615	125000		269				376
920618	151500		260				342
920623	151500		254				319
920626	152000		261				346
920629	113500		261				346
920702	153000		263				353
920707	142000		262				349
920710	143000		270				380
920714	150000	137	267	388	4.9	19	368
920720	123000		260				342
920727	122000		268				372
920729	163500		269				376
920731	161000		268				372
920807	115500	143	268	383	6.6	25	372
920811	170000		271				383
920821	144000		283				429
920902	104000	151	321	583	7.1	41	573

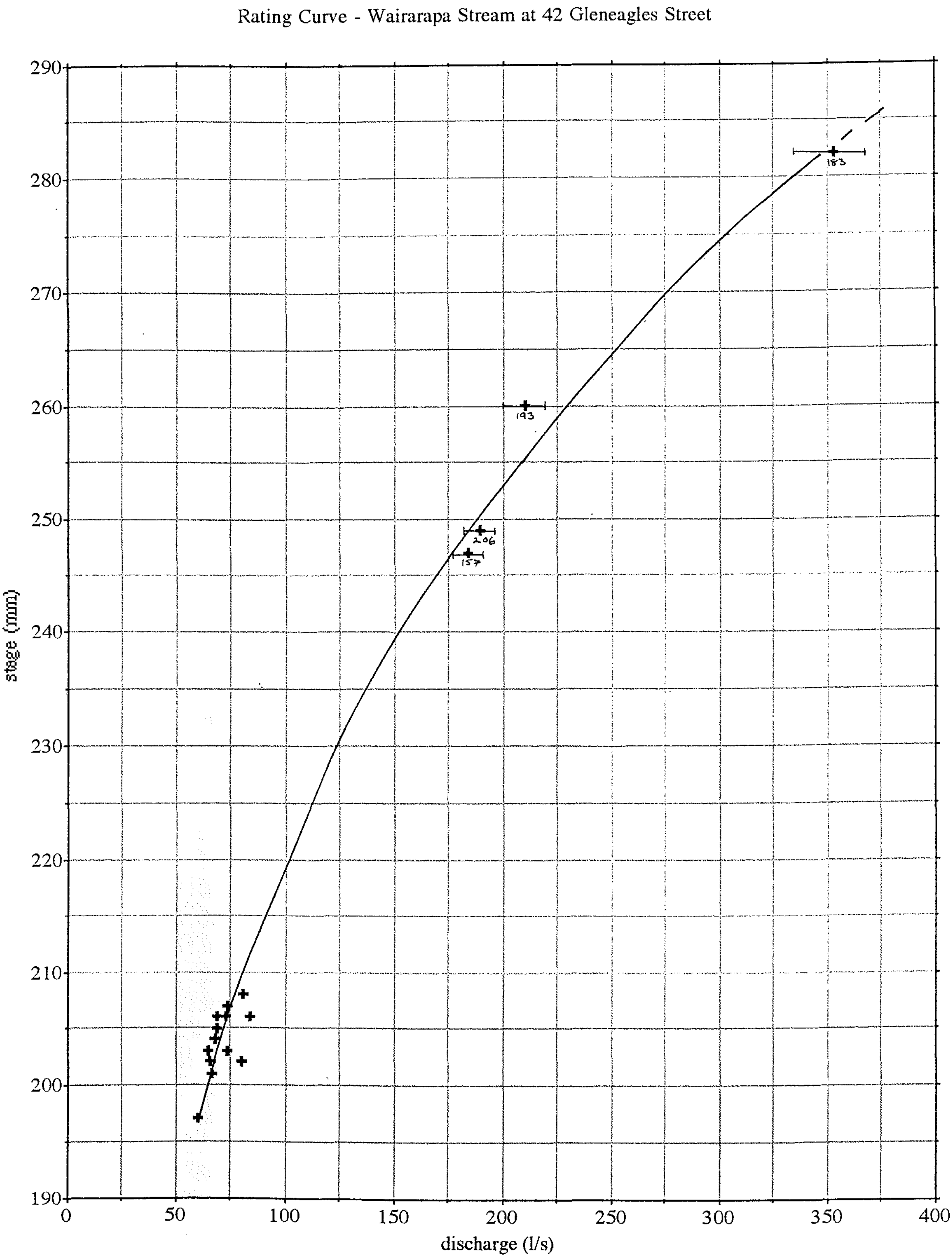
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920904	112000		304				508
920913	161500		317				558
920922	132500		331				611
920925	163000		334				622
920929	161500	170	332	569	6.4	51	615
921001	133000		312				539
921007	124000		322				577
921012	144200		322				577
921021	122000		340				645
921030	120000		340				645
921102	131000		333				610
921109	134000		333				600
921124	114500		337				570
921207	125500	196	330	528	7.1	45	528
921222	110500		329				500
930107	152500		340				537
930120	130000	210	340	508	7.1	43	537

Rating curve - Wairarapa Stream at Garden Road



Appendix 3.12 Wairarapa Stream at 42 Gleneagles Tce Site 66647							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920223	125000	8	204	68	11	7	72
920227	105000	15	203	65	10.6	7	71
920305	123000	26	203	74	11	8	71
920308	144000		208				78
920310	123000	35	207	72	10.3	7	76
920320	121500	52	205	69	10.5	10	74
920325	112000	63	201	67	10.1	7	68
920405	115500	75	202	80	10.1	8	70
920408	140000		201				68
920415	110000	86	202	66	7.1	5	70
920422	120000		203				71
920424	171500		203				71
920427	134500	92	206	69	7.6	4	75
920430	160500		212				84
920505	132500		203				71
920511	142500		204				72
920513	145000		203				71
920516	164000		207				76
920518	93500	101	206	73	9.1	7	75
920521	161000		183				15
920526	142000		207				76
920529	140500		204				72
920602	163000		202				70
920604	121000		197				60
920611	104500	113	208	81	8.6	7	78
920615	135000		203				71
920618	160000		209				79
920623	141000		190				41
920626	161500		201				72
920701	125500	124	208	100	11.5	12	78
920702	125500		208				78
920707	161000		202				70
920709	114500		208				78
920710	145500		204				72
920714	134000	134	206	84	8.9	7	75
920720	110500		193				50
920727	115000		196				58
920729	162000		210				81
920731	151500		205				74
920807	102000	140	197	60	9.2	6	60
920811	173000		201				68
920821	141000		216				92
920902	142500	157	247	184	5.2	10	179
920904	105500		227				119

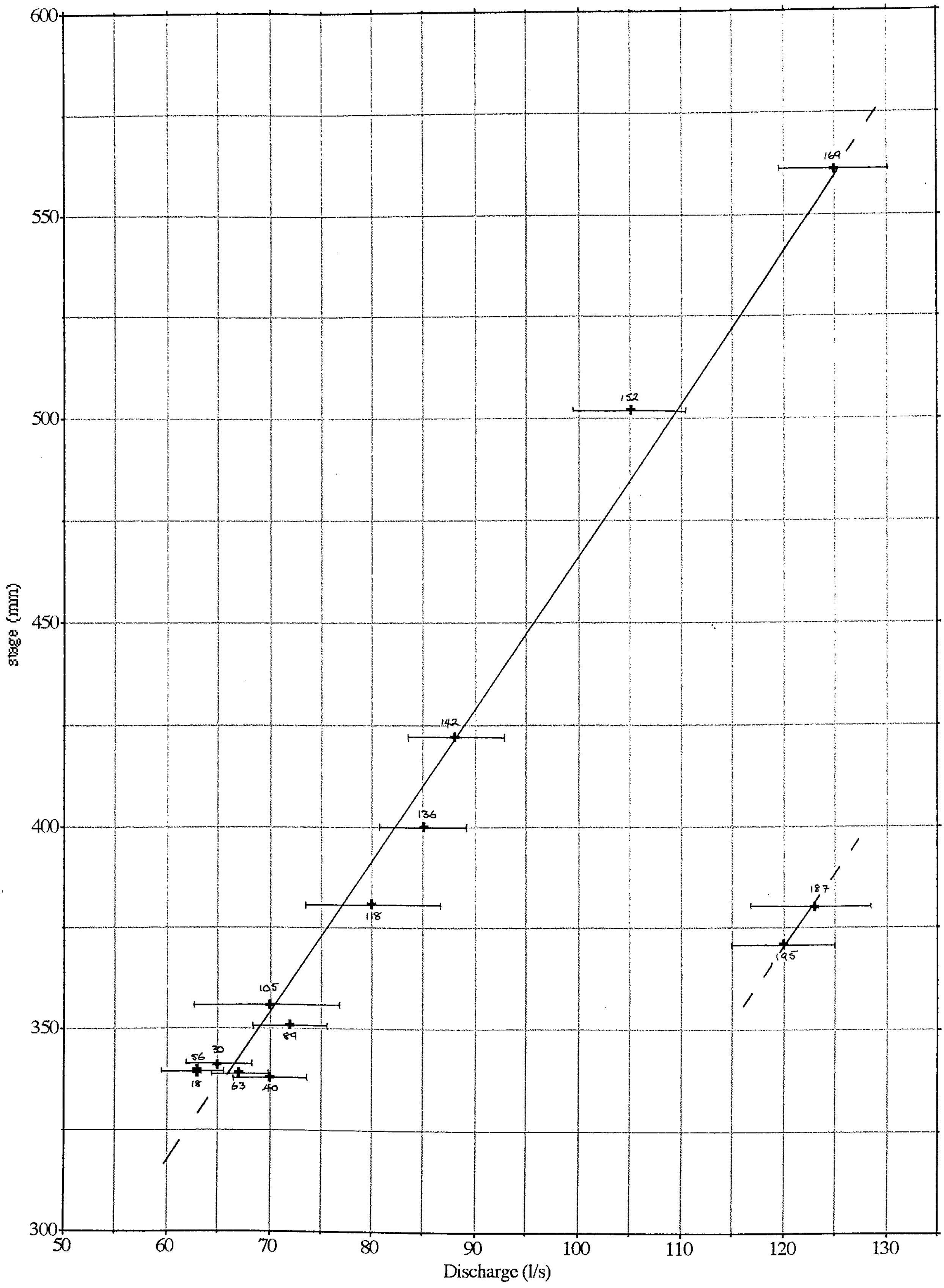
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920913	152500		239				150
920922	115000		252				196
920925	141000		255				208
921001	154500		267				265
921007	133000		272				291
921021	171500		271				286
921029	115000	179	282	353	8.7	31	353
921103	114500		274				302
921109	114500		273				296
921124	105000		263				245
921207	140000	193	260	210	8	17	231
921222	104000		252				196
930107	150500		250				189
930112	133000	206	249	190	9.2	17	186


Rating Curve - Wairarapa Stream at 42 Gleneagles Street
stage (mm)
discharge (l/s)
290
280
270
260
250
240
230
220
210
200
190
0
50
100
150
200
250
300
350
400
183
193
206
157

Appendix 3.13 Taylors Drain at Elmwood Park Site 66646							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920220	153000	6		61	10.6	7	67
920227	131500	18	340	63	9.7	6	67
920306	102000	30	341	65	9.7	6	67
920308	160000		340				66
920310	163000	40	338	70	9.1	6	66
920320	152500	56	338	63	9.7	6	66
920325	140500	66	339	67	9.3	6	67
920327	135000		340				71
920405	150000		357				69
920408	150000		349				69
920413	160000		349				69
920415	134000	89	351	72	10.1	7	69
920422	133500		348				68
920424	164500		346				70
920427	150000		352				70
920430	144500		352				70
920505	140500		352				73
920511	145500		366				72
920513	161000		359				71
920516	153000		357				71
920518	113500	105	356	70	9.3	13	76
920521	163000		377				76
920526	131500		375				74
920529	144000		369				73
920602	170500		364				72
920604	124000		362				77
920611	154500	118	381	80	9.7	12	80
920615	124500		392				77
920618	151000		380				77
920623	151000		380				78
920626	151500		382				78
920629	114500		383				79
920702	152500		386				80
920707	143000		389				78
920710	143500		383				82
920714	161000	136	400	85	10.1	8	77
920720	124000		380				84
920727	122500		407				88
920729	163000		420				88
920731	160500		420				88
920807	124000	142	422	88	8.9	10	89
920811	170500		426				95
920821	143700		449				109
920902	171500	152	502	105	9.5	11	105

Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920904	112500		485				111
920913	161000		509				120
920922	132000		541				123
920925	163500		552				125
920929	152000	169	561	125	9.1	11	125
921001	132000		561				125
921007	124500		389				124
921012	144000		386				123
921021	122000		390				124
921030	115500		382				122
921105	135500	187	380	103	10	9.3	121
921109	133500		380				121
921124	114000		375				119
921207	125000	195	371	100	10.3	10	117
921222	110000		377				120
930107	152000		397				127

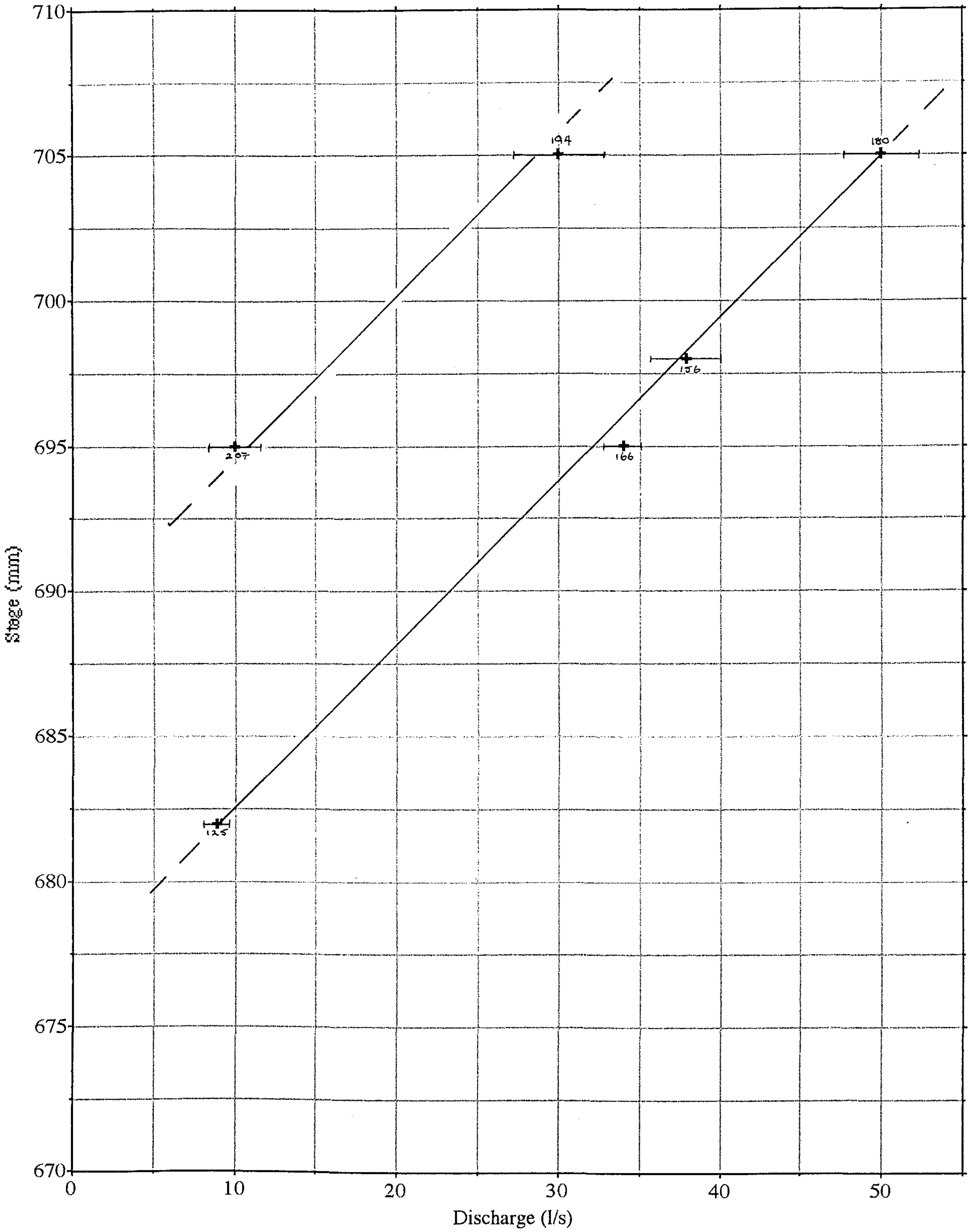
Rating Curve - Taylors Drain at Elmwood Park



Appendix 3.14 Wai-iti Stream at Clyde Road Site 66648							
Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
920308	145000		646				4
920310	124000		644				4
920325	113000		639				3
920405	120500		652				5
920408	111000		649				4
920415	111000		650				4
920424	122000		656				5
920427	171000		657				5
920430	155500		658				5
920505	133500		660				6
920511	143000		678				8
920513	145500		678				8
920516	163500		660				6
920521							
920526							
920529							
920602							
920604							
920611							
920615							
920618							
920623	123500		683				10
920626	161000		687				17
920629	171500		679				9
920701	134000	125	682	9	10.1	1	9
920707	161500		678				7
920710	144500		676				8
920714	160000		672				7
920720	111000		677				8
920727	120000		675				8
920729	162500		672				7
920731	152000		670				7
920807	114000		669				7
920811	172500		669				7
920821	143000		672				7
920902	134500	156	698	38	9.4	4	38
920904	110000		695				32
920913	163500		699				40
920922	120500		695				32
920925	150000	166	695	34	7.3	2	34
921001	140000		696				59
921012	143500		702				45
921021	172000		703				47
921029	125500	180	705	50	9.2	5	50

Date	Time	Gauge #	Stage (mm)	Gauged Discharge (l/s)	Gauging Error %	Gauging Error Range (l/s)	Rated Flow (l/s)
921103	115000		700				41
921109	115000		698				36
921124	105500		695				
921207	120500	194	705	30	8.9	4	30
921222	104500		700				
930107	151000		699				
930115	143000	207	695	10	9.5	3	10

Rating Curve - Wai-iti Stream at Clyde Road



Appendix 5.1 Groundwater levels recorded during this study (meters amsl)

Date	M35/5220 Athol Tce	M35/3169 Thurlstone Tce	M35/3775 Greers Rd	M35/3785 Taylors Ave	M35/3921 Glandovey Rd	M35/5409 Matai St	M35/4367 Ngahere St
920413		14.628		10.42	9.63	15.11	10.36
920422	11.61	14.648	13.62	10.43	9.636	15.08	10.39
920501	11.63	14.688	13.61	10.43	9.64	15.05	10.46
920507	11.64	14.708	13.6	10.44	9.65	15.06	10.37
920516	11.84	14.788	13.71	10.51	9.71	15.06	10.47
920526	11.75	14.718	13.78	10.52	9.69	15.06	10.47
920603	11.74	14.678	13.79				
920604				10.39	9.66	15.04	
920615	11.84		13.82	10.57	9.72	15.03	10.52
920616		14.868					
920626	11.88	14.898	13.91	10.52	9.69	15.03	10.5
920707	11.82	14.928	13.8	10.53	9.71	15.02	10.51
920720	11.9	14.978	13.95	10.53	9.72	15.01	10.51
920731	11.91	15.018	13.88	10.53	9.7	14.98	10.52
920807	11.91	15.048	13.89	10.53	9.78	14.98	10.5
920813	11.95	15.088	13.92	10.6	9.73	15	10.49
920819	11.98	15.088	13.96	10.84	9.73	15	10.6
920903	12.35	15.678	14.44	10.72	9.87	15.33	10.72
920914	12.57	15.878	14.55	10.73	9.87	15.32	
920922	12.75	16.098	14.63	10.71	9.84	15.34	10.8
920929	12.96	16.298	14.8	10.74	9.87	15.31	10.85
921007	13.16	16.508	14.92	10.75	9.87	15.33	
921021	13.35	16.648	14.94	10.77	9.9	15.37	10.96
921030	13.4	16.648	14.93	10.76	9.88	15.32	10.96
921109	13.3	16.518	14.8	10.7	9.84	15.3	10.9
921124	13.15	16.318	14.66		9.82		
921126				10.68		15.57	10.86
921207	12.99	16.208	14.6	10.67	9.8		
921209						15.54	10.79
921222	12.82			10.65	9.8	15.53	10.77
930107	12.68	15.898	14.45			15.49	

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